64-8

FTD-TT- 62-859

TRANSLATION

PRODUCTION TECHNOLOGY OF MINIATURE GYROMOTORS

By

S. A. Zholdak

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

OHIO

PAGES ______

ARE

MISSING

IN

ORIGINAL

DOCUMENT

FTD-TT- 62-859/1+2

UNEDITED ROUGH DRAFT TRANSLATION

PRODUCTION TECHNOLOGY OF MINIATURE GYROMOTORS

BY: S. A. Zholdak

English Pages: 357

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

S. A. Zholdak

TEKHNOLOGIYA IZGOTOVLENIYA MALOGABARITNYKH GIROMOTOROV

Gosudarstvennoye Soyuznoye Izdatel'stvo
Sudostroitel'noy Promyshlennosti
Leningrad 1961

Pages: 1-267

FTD-TT-62-859/1+2

TABLE OF CONTENTS

The present volume considers problems of the production technology of components and units and also the assembly and testing of one of the basic elements of any gyroscopic instrument — the gyromotor. The principal attention is devoted to the technology of the miniature electric gyromotor. Devices used to ensure high manufacturing precision are described.

The material of the book is arranged in the sequence in which the components are usually finished and the units assembled in the production of gyromotors.

The book is intended for perusal by engineering-technical workers in the instrument-building industry. It may also be useful to students majoring in instrument building in the higher technical schools and to students in the intermediate technical educational institutions.

INTRODUCTION

The gyromotor, which is the basic element of any gyroscopic instrument, exerts a decisive influence on the precision delivered by the instrument and the dependability of its performance. As a rule, if it is to meet the given precision specifications, a gyroscope must possess a large angular momentum within the dimensions reserved for it, high stability of the position of its center of gravity, high constancy of the angular momentum, a low vibration level, and so forth. In many respects, the dependability of performance of a gyroscope depends on the margin of safety given its high-speed ball bearings, the strength margin of the rotor flywheel, and the dielectric-strength margin of the insulation. However, securing these last requirements depends not only on correct selection of the basic parameters for the gyroscopic instrument and its physical design, but also on proper technology in fabricating the components and units of the gyroscopic system.

The basic production tasks that must be discharged in the manufacture and testing of gyroscopic instruments are as follows:

1. Securing high surface-roughness classes in the components, particularly at seating points.

This is necessary to reduce the number and height of the high spots on the component surfaces, and the number of foreign particles left on them after machining, as well as to make it possible to clean these particles from the components. Meeting this requirement (to-

Chapter 1

THE PHYSICAL DESIGNS OF GYROMOTORS

§1. THE GYROSCOPE AND ITS PRECESSION

The basic element of any gyroscopic instrument is its high-speed rotor. The rotor 1 of the gyroscope (Fig. 1), which is mounted on two supports in the internal gimbal ring 3, has freedom to rotate about the axis AA. The inner ring 3 can turn freely about its axis BB on supports carried in the outer gimbal ring 2. The outer ring rotates freely about the outer axis CC in supports mounted in the instrument housing K. All three of these axes must be pairwise mutually perpendicular and must intersect at a single point O known as the suspension point of the gyroscope. The axes AA, BB, and CC are, respectively, known as the main, inner, and outer axes of the gyroscope suspension. By analogy with the suspension axes, the supports that provide for rotation of the rotor about the axis AA are known as the main supports of the suspension, or simply the main supports, while the supports that provide for rotation about the axes BB and CC are known as the suspension supports.

The gimbal suspension permits the gyroscope freedom of rotation about the three axes AA, BB, and CC and thereby permits the axis AA of the rotor to assume any position in space. Depending on the number of axes in the suspension, gyroscopes have two or three degrees of freedom. In the gyroscope model being described (Fig. 1), the rotor can turn about the three axes AA, BB, and CC. Such a gyroscope is

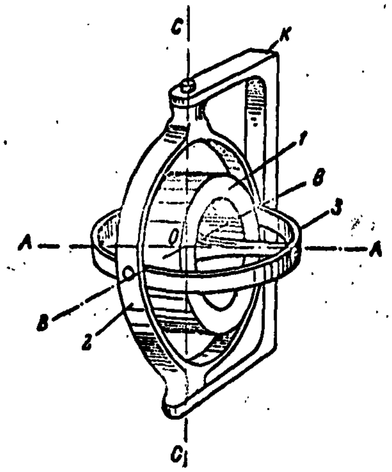


Fig. 1. The gyroscope with its gimbal suspension.

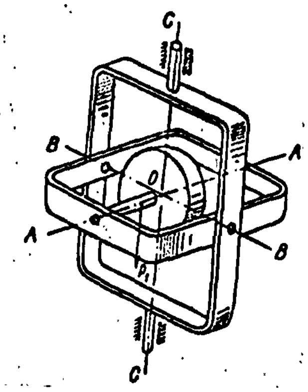


Fig. 2. Influence of bearing clearances on precision of gyroscope.

normally known as a gyroscope with three degrees of freedom. If in such a gyroscope one ring of the suspension is made stationary, the gyroscope will have only two degrees of freedom. Depending on the number of degrees of freedom, the gyroscope acquires the various properties that are extensively exploited in engineering.

The gyroscope rotor is most frequently driven either pneumatically or by an electric drive. In either case, the power of the motor must guarantee rotation of the rotor at high speed (tens of thousands of rpm), and its design must guarantee constancy of the operating speed of the rotor and trouble-free work at this speed for long periods of time under conditions in which the temperature varies sharply and the base of the instrument vibrates and is subject to accelerations. Gyroscopic instruments operate under difficult climatic conditions and severe mechanical disturbances. The instruments and, consequently, the gyroscopes with their gyromotors, must operate without failure at temperatures from + 50 to – 60° and with 80-cycle vibrations at an amplitude as high as 0.15 mm and withstand occasional severe shocks. Through all this, the precision of the

readings and dependability must be maintained over long periods of operation.

Constancy of the position of the gyroscope's center of gravity with respect to its housing is of great importance to the performance of a gyroscopic instrument. Thus, for example, when the center of gravity of the rotor is shifted along the axis AA (Fig. 2) by an amount equal to the shaft clearance in the main supports, there arises a precessional movement of the gyroscope about the axis CC with an angular velocity

$$\omega = \pm \frac{Pa}{I\Omega}, \tag{1}$$

where ω is the angular rate of precession, P is the rotor weight, $\underline{a}$ is the clearance, I is the rotor's moment of inertia, and Ω is the angular velocity of the rotor.

It follows from the equality given above that the shaft clearances in the main supports of the gyroscope must be reduced to the smallest possible value. This is usually achieved by tensioning the main supports, which results in an increase in the frictional moment in them and thereby, as a rule, an increase in the power of the motor used to drive the gyroscope rotor. This deficiency is offset by the reduction in the main-support shaft clearances and the increase gained in the over-all precision of the gyroscopic instrument.

Equation (1) expresses the law of precessional motion or, in brief, that of gyroscope precession, which is basic to the elementary theory of gyroscopic phenomena. It follows from the equation that the velocity ω increases as long as the applied torque is increased. When the effective torque is constant, the angular velocity of precession remains constant and the precessional motion ceases after the torque has ceased to act. Here, the rotation of the main gyroscope axis AA will take place not in the plane in which the torque is applied but

in a plane perpendicular to it along the axis CC (Fig. 2).

§2. BASIC DESIGN VARIETIES OF GYROMOTORS

The precision, sensitivity, and service lives of gyroscopic instruments depend basically on the design of the gyromotor, the precision with which its components and assemblies are fabricated, the quality of the main supports, and the magnitude of the angular momentum $I\Omega$ of its rotor.

Let us examine certain designs for miniature gyromotors with electric drives.

Electric gyromotors, which operate on direct and alternating current, are inverted-type electric motors. In such gyromotors, the stator is located inside the rotor, thus giving an increase in the rotor's moment of inertia and, consequently, in its angular momentum as well; as noted above, the precession rate of the gyroscope is a function of the latter. An increase in the rotor moment of inertia can be achieved by increasing its mass and distributing it as far as possible from the axis of rotation. The possibility of increasing the rotor speed is limited by the service lives of the main-support ball bearings, i.e., the time for which they can perform dependably in hours. Retention of stability in the gyroscope indications requires constancy of the rotor angular momentum, and this can be guaranteed only if the gyromotor rotor is turning at constant speed. Consequently, the prime requirement set forth for the gyromotor selected is that of retention of constant angular velocity irrespective of load. Parallel-excited direct-current motors and alternating-current induction motors possess rigid mechanical characteristics of this type that are adequate for practical use in gyromotors.

Direct-current gyromotors (Fig. 3) are conveniently used when a direct-current line is available, since they can be connected directly

to the line and have only two lead wires. Essential shortcomings of direct-current gyromotors are the presence of the collector, which complicates their design, the comparatively rapid wear of the collector and brushes, and sparking of the sliding contact, which gives rise to radio noise, so that direct-current gyromotors have not come into extensive use in gyroscopic instruments.

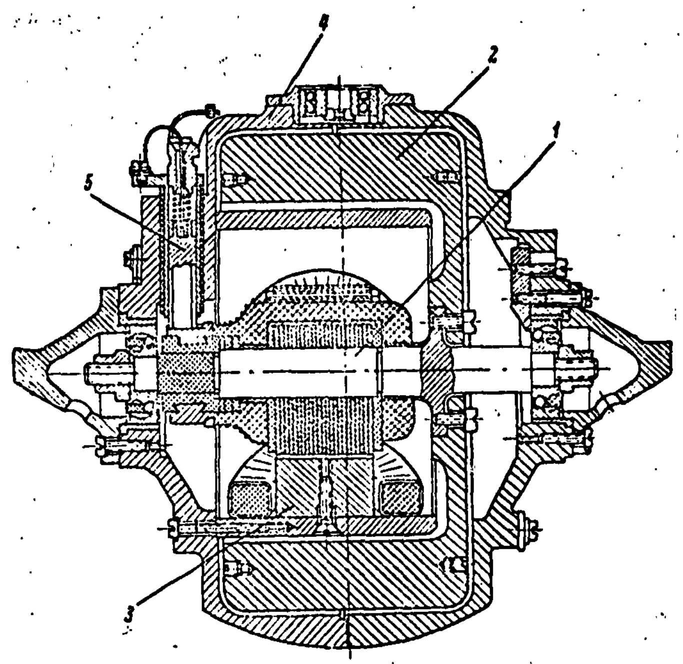


Fig. 3. Direct-current gyromotor. 1) Rotor with winding; 2) flywheel; 3) stator with coils; 4) gyroscope housing; 5) brush.

Alternating-current motors have come into extensive use; these are three-phased two-pole induction motors whose shunt-wound rotors function simultaneously as the gyroscope rotors, while their three-phase-wound stators are located inside the rotor and secured to the gyroscope-chamber cover. The latter is mounted on the gyroscope-chamber housing, which simultaneously functions as the inner gimbal-suspension ring of the gyroscope. The stator winding is fed off a special high-frequency three-phase converter at about 350-1000 cycles, thus guaran-

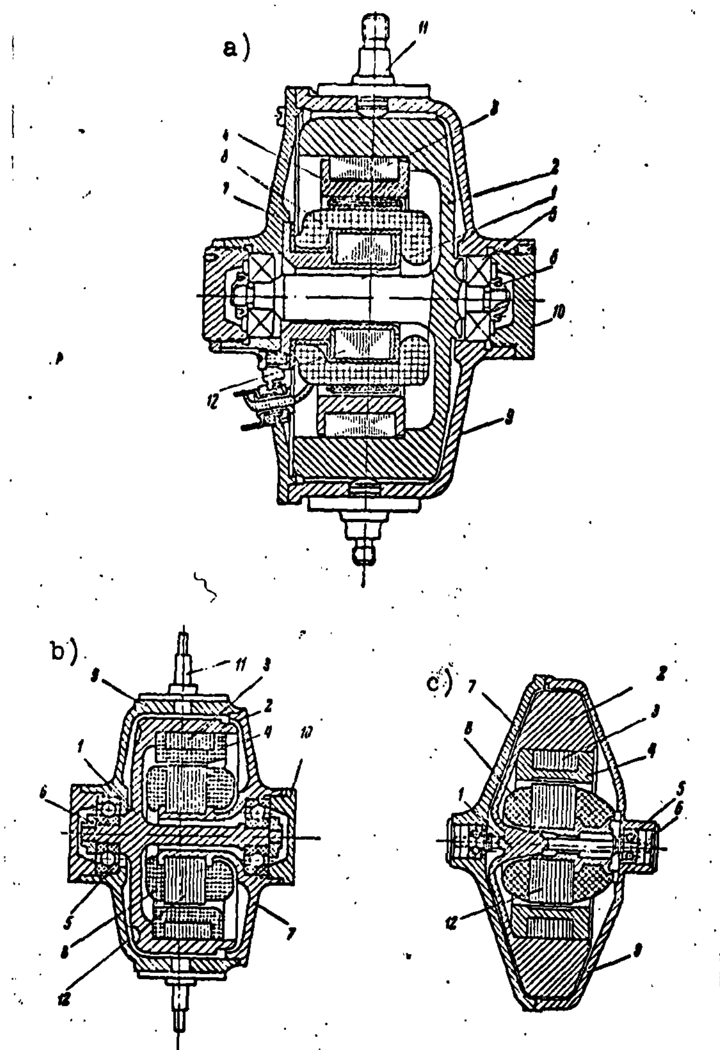


Fig. 4. Alternating-current gyromotors: a) with screw-mounted cover; b) with inside-threaded cover; c) with horseshoe rotor and screw attachment of cover.

teeing the necessary rotary speed and, consequently, the required angular momentum of the gyromotor rotor.

Figure 4 shows certain designs for miniature alternating-current electric gyromotors that are used in contemporary gyroscopic instruments. As will be seen from the figure, all of the gyromotors have a rotor 1 placed inside the gyroscope chamber and consisting of a fly-

wheel 2 with the magnetic-circuit pack 3, the slots of which are filled with the shunt winding 4, press-fitted inside it. The ball bearings 5 are seated on the necks of the rotor shaft. The inner ball-bearing race is pressed onto the rotor-shaft neck with a force sufficient to provide a press fit without deformation of the ring, and further secured by the nut 6.

The rotor is carried by its ball bearings – which are known as the gyroscope's main-support bearings – between the housing hole 9 at one end of the gyroscope chamber and the cover hole 7 at the other end. The housing and cover of the gyroscope chamber are joined by means of screws (Figs. 4a and 4c) located around the rim of the housing, or a threaded joint is made (Fig. 4b) with the purpose of reducing the size of the gyroscope chamber.

In some gyromotor designs, the gyroscope chamber consists of two covers and a strap. The strap is a ring as wide as the rotor flywheel is long and has a hole to provide for free rotation of the rotor. The journals 11 are secured to the outside of the strap, which serves as the inner gimbal ring. The gyroscope-chamber covers are attached to the strap by mounting screws threaded directly into the rim of the gyroscope-chamber ring.

Special ventilation holes are made in the housing and covers of the gyroscope chamber to permit cooling of the gyromotor windings.

The stator package 12 with the windings 8 is secured to the cover; its outer diameter is received by the rotor-package bore with an air gap that is rigorously uniform around the entire circumference. The special bearing covers 10, which fix the position of the ball bearings and thereby that of the rotor in the gyroscope chamber are turned from the outside into the threaded parts of the main-support-bearing holes in the cover and housing; with magnetic

ball bearings, apart from positive location, they eliminate the shaft clearance and set up the necessary tension on the bearings when they are tightened. The tension is reduced after a few hours of operation by running-in of the rubbing surfaces. During subsequent operation, the tightness and the shaft clearance vary only insignificantly and may be regarded as constant.

As was discussed earlier, the shaft clearance in the main supports due to displacement of the gyroscope's center of gravity is responsible for precessional motion. To eliminate the shaft clearance and prevent possible jamming on thermal expansion of the support components, certain designs make provision for a special spring-type temperature compensator. When magnetic ball bearings are used, it is regarded as possible to omit the compensators on the assumption that the linear expansion of the shaft and other components of the bearing unit will give rise only to reduced shaft clearance and result in an increased frictional moment.

Gyromotor ball bearings operate at high speeds reaching 30,000 rpm and higher. The quality and amount of lubricant used acquires great significance for their service lives and corrosion resistance. A very thin oil flim is sufficient for normal operation of the ball bearings, so that rolling of the balls along the races and friction against the separator will take place under the conditions of fluid friction. Hence the ball bearings must always be lubricated during operation, and a strictly determined quantity of lubricant must be placed in them in final assembly. Moreover, extra lubricant must be laid into the bore of the bearing cover 10; on evaporation, this will envelop all components of the ball bearings in an oil mist. In certain gyromotor designs, replenishment of the lubricant during operation is provided by placing a greased wick or felt disk impregnated

with liquid lubricant into the seat. Designs exist in which the lubricant is replenished through special funnels provided in the bearing covers.

Rotors

Alternating-current gyromotor rotors are flywheels the basic mass of which is located at the rim, which is attached to the hub or shaft by a thin disk. As was indicated earlier, the precision and sensitivity of any gyroscopic instrument will be the higher the larger the value of its angular momentum. In practice, however, increases in this angular momentum are limited by technical considerations. Thus, increases in the moment of inertia I of the rotor are limited by the dimensions of the gyromotor and by its weight. On the other hand, increases in the angular velocity Ω of the rotor are limited by the stresses that can be tolerated by the flywheel material and the service life of the ball bearings. This is why rotor flywheels must be made from a strong, uniform, and satisfactorily machine material of high specific gravity. Chromium-manganese, chromium-nickel and high-carbon steels conform to these specifications. In certain precision high-speed gyromotors, the flywheels are made from high-alloy steel of type 35KhMYuA steel.

Figure 5 shows the physical design and configuration of rotor flywheels used in miniature alternating-current gyromotors, while Table 1 lists their characteristics.

To reduce ventilation losses, i.e., losses due to friction against the air, on which as much as 85-95% of the power drawn by the gyromotor may be expended, the rotors are given streamlined shapes and polished on the outside.

The rotor packets of the electric motors are assembled from individual plates stamped from electrical steel and carrying slots uni-

formly arranged around their internal diameters. The slots of the pack are filled with aluminum or an aluminum alloy. The result is a shunt-wound rotor. Such rotors are precision-machined and coated with a thin anticorrosion film.

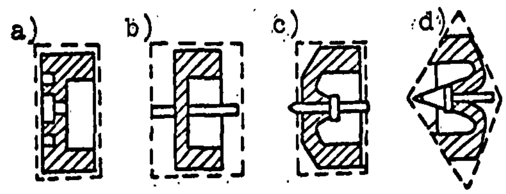


Fig. 5. Rotor flywheels for alternating-current gyromotors.

TABLE 1

Characteristics of Rotor Flywheels for Miniature Electric Gyroscope Motors

1) Наружный диаметр D, мм	2) Вес Q, $Г$	3) Осевой момент инерции I, $Гсмсек^2$	4) Угловая скорость вращения Ω, 1/сек.	5) Кинетический момент $I\Omega$, Гсмсек	6) $\frac{\Omega}{I\Omega}$, 1/смсек
30	57,8	0,072	2753	198,9	0,292
40	114	0,294	3140	924	0,1140
50	182	0,73	3012	2282	0,0795
50	300	1,09	1588	1740	0,1725
60	350	2,06	3130	6450	0,0543
60	700	3,5	2094	7330	0,0955
70	555	4,38	3133	13 700	0,0405
72	714,6	5,21	1885	9821	0,0727
75	788	6,5	1885	12 252	0,0643
100	1330	27,79	2954	82 250	0,0162

1) Outside diameter D, mm; 2) weight Q, gf; 3) axial moment of inertia I, gf-cm-sec^2; 4) rate of rotation Ω^{-1}; 5) angular momentum $I\Omega$, gf-cm-sec; 6) $\Omega/I\Omega$, cm^{-1}sec^{-1}.

The flywheel with the shunt winding pressed into it should be statically and dynamically balanced with the highest possible precision. In the presence of static imbalance, centrifugal inertial forces that change direction with a frequency equal to the rotor rpm's will arise when the rotor turns. These high-frequency repeated loads are absorbed directly by the bearings of the gyroscope suspension. Since the balls have virtually no play with respect to the bearing ring, the loads are transmitted through the balls to the same

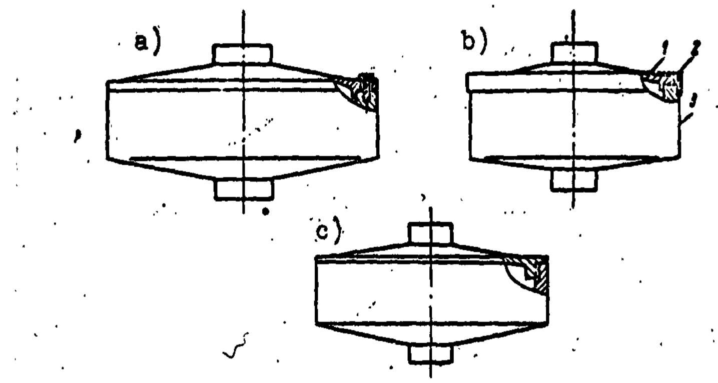


Fig. 6. Attachment of covers to housings: a) Screws; b) with internal thread; c) with special ring.

points on the bearing rings. As a result, depressions are formed on the suspension-bearing races, and this sharply increases the frictional moment in the suspension supports and raises the precession rate of the gyroscope and, consequently, reduces its accuracy. Dynamic imbalance results in the appearance of large-amplitude forced oscillations of the gyroscope, which usually increase the angular rate of its precession.

Housings

The gyromotor housing serves simultaneously as the gyroscope chamber in which the rotor turns, and as the inner ring of the gyroscope's gimbal suspension. The housings are made by casting from aluminum or magnesium alloys or by hot stamping [drop forging] from steel with subsequent machining. The housings must be machined with very high precision. This applies particularly to the bore of the holes for the gimbal-suspension shafts, the cover catch, the precision of which provides for correct location of the stator in the rotor bore with the necessary air gap, and to the holes in the housing and cover for the main-support ball bearings. The inside surface of the housing must be machined to high finish to reduce ventilation

losses.

In certain precision-gyromotor designs, the gyroscope chambers, which consist of a housing and a cover, are made hermetic with the objective of achieving a sharp reduction in ventilation losses and, consequently, in the power drawn by the gyromotor. The air is evacuated from such a gyrochamber after final assembly of the motor, and the rotor turns in a vacuum. In some designs, the gyrochamber is filled with rarefied hydrogen.

The housings have a cylindrical cavity in which the cylindrical rotor turns. The designs of the housing outer surface differ in the attachments of the journals and the method used to secure the covers to them.

Figure 6 shows certain designs for the housings of miniature gyromotors with the covers attached in various ways. Figures 6a and 4a and 4c show methods of attaching the covers to the housings by means of screws as used in general-purpose gyromotors. In the design shown in Figs. 6b and 4b, the cover is threaded to the housing to reduce the over-all dimensions of the gyromotor. In these designs, the outside diameter of the cover is increased by reducing the rotor diameter over a short segment of its width (Fig. 4b) with the object of permitting the use of normal threads. Figure 6c shows the design of a housing in which the cover 1 fits tightly into the locking groove, is located in it by a small pin, and pressed to the housing by a special ring 2 which is screwed onto the outside thread of the housing 3, thus eliminating the possibility of the cover shifting along the main axis.

Covers

Like the housings, gyromotor covers are fabricated by casting from aluminum or magnesium alloy or by hot stamping from steel with

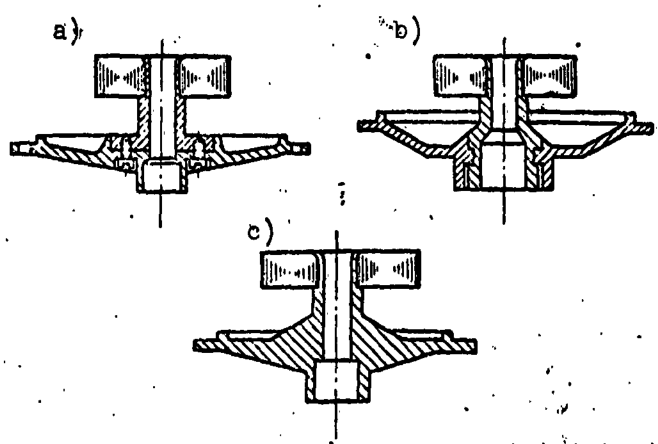


Fig. 7. Attachment of covers to housing and of stators to covers: a) With Screws; b) with outside thread on catch; stator is secured to bushing cast integral with cover; c) with threaded ring; stator is mounted on steel bushing reinforced during casting of the cover.

subsequent machining. The covers differ from one another in design in having different methods for securing them to the housings, as was described above, and for attachment of the wound stator packs to them.

Figure 7 shows designs of gyromotor covers with different ways of securing them to the housings and the stator packs to them. Figure 7a shows a cover secured by a tight fit between its groove and the catch on the housing, thus guaranteeing concentricity of their diameters. To prevent the cover from shifting along the main housing axis, it is bolted to the face of the housing. The iron pack of the stator may be secured to the cover by various methods (Fig. 7).

The stator packs are assembled from stamped plates of electrical steel with slots arranged around their outside diameters at uniform intervals, and are press-fitted into special steel bushings the face ends of which are then expanded to secure the plates in position. The stator winding is laid into the slots of the stator pack and impregnated with a special lacquer to improve its insulation resistance.

Main-Support Ball Bearings of Gyroscope

Contemporary miniature gyromotors make use of high-speed precision ball bearings that simultaneously absorb axial and radial loads and have minimal clearances. The ball bearings used in gyromotors operate under severe conditions at speeds attaining 60,000 rpm. They must deliver trouble-free performance through sharp temperature fluctuations, shocks, and vibrations, and withstand 12 short-term overloads lasting up to 3 minutes.

Special high-speed radial-thrust ball bearings conform to these high specifications.

Two types of ball bearings are used in miniature gyromotors: single-row radial sealed types with metallic separators and knock-apart radial-thrust types with textolite or nylon separators.

Single-row radial ball bearings (Fig. 8) are capable of absorbing, in addition to the radial load, the axial loads acting in either direction along the rotor axis (the magnitude of the axial load may not exceed 70% of the admissible radial load for a given theoretical service life). The ability to absorb axial loads in either direction makes it possible to locate the rotor in the housing with a minimal axial clearance.

Figure 9 shows in assembled form, and Fig. 10 in disassembled form a radial-thrust (magnetic) ball bearing designed to absorb combination loads acting in the radial and axial directions. To provide for location of the rotor in both directions, ball bearings of this type must be mounted in pairs; this makes it possible to effect a preliminary negative clearance.

The ball bearings consist of outer and inner rings, a textolite or nylon separator, and the balls. While the axial clearance is constant in single-row radial ball bearings, it may be adjusted by

shifting one of the rings axially in the case of the radial-thrust bearings. Magnetic ball bearings can be disassembled and washed before final assembly of the gyromotor without disturbing the positioning of the ring on the rotor shaft; this is one of their advantages over the radial inseparable [sealed] types.

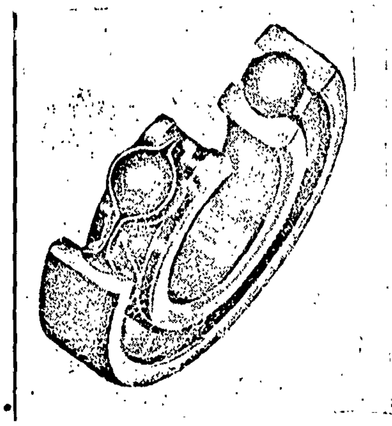


Fig. 8. Single-row radial ball bearing.

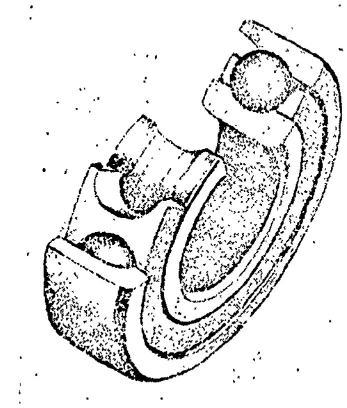


Fig. 9. Knock-apart radial-thrust ball bearing.

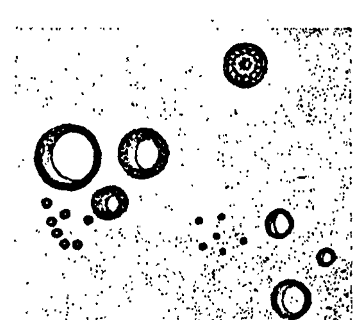


Fig. 10. Disassembled radial-thrust ball bearings of types 6005 and S-23.

The ball bearings used in gyromotors are manufactured and delivered in accordance with special technical specifications and drawings and GOST 520-55, including Paragraph 36 (with the exception of point f) to precision class S, with the necessary supplements and revisions.

Ball bearings must meet the following basic specifications:

- they must possess minimal frictional moments;
- they must be demagnitized;
- they must conform to stipulated service-life requirements;
- they must be corrosion-resistant;

TABLE 2

Precision Tolerances for Ball Bearings

1) Наименование параметра	2) Допуски, мк	
	3) внутреннее кольцо	4) наружное кольцо
5) Допуски на точность обработки посадочных поверхностей:		
6) овальность	5	4
7) конусность	3	2
8) Разностенность	5	5
9) Боковое биение торца	4	—
10) » » по дорожке качения	3	3
11) Овальность дорожки качения	2	3
12) Радиальный зазор подшипника	20—35	

Примечание. Указанные допуски относятся к контролю деталей разобранных подшипников. Разноразмерность шариков в любых сечениях в одном шарикоподшипнике не должна превышать 0,005 мм.

Note: The tolerances indicated refer to control of the disassembled bearing components. The dimensional variation of the balls in all sections may not exceed 0.005 mm in a single ball bearing.

1) Parameter; 2) tolerances, μ; 3) inner ring; 4) outer ring; 5) tolerances for machining finish on seating surfaces; 6) oval; 7) taper; 8) wall-thickness variation; 9) lateral lash of face; 10) lateral lash against race; 11) oval race; 12) radial clearance of bearing.

— they must conform to special tolerances and shape precisions indicated in the drawings and specifications.

The dimensional tolerances may not exceed the values indicated in Table 2.

The quality of the metal used in the rings and balls as regards nonmetallic inclusions must be guaranteed by special selection from chromium bearing steel in accordance with GOST 801-58; there must be not more than two points for oxides and not more than one for sulfides.

The roughness of the rolling surfaces of ball-bearing unit components exerts considerable influence on service life. The most critical work is that of a surface layer a few tens of microns thick on the races and balls. It has been established by practical experience

that the greater the unevenness on the races, the more severe will be the wear per unit operating time and, consequently, the shorter will be the service life of the ball bearing. For this reason, rigid specifications are set forth for the roughness of the working and mounting surfaces of the ball bearings. The roughness on these surfaces of the ball-bearing components must correspond to the following classes of GOST 2789-59:

a) class 12 for the working surfaces of the rings;

b) class 12 for the working surfaces of the balls;

c) class 9 for the inner surfaces of the inner rings;

d) class 9 for the outer surfaces of the outer rings;

e) class 8 for the faces of the rings.

Pits and scratches no larger than those shown on special photographic standards with which the manufacturer is supplied are tolerated on the working surfaces of the rings and balls during preassembly quality control. The surface roughness of the balls is usually checked on a Linnik (MII-4) microinterferometer. The microinterferometer may be used to measure roughness with an error of 0.25 of the interference-band width, i.e., normally to 0.06 μ.

A modern polishing method – hydropolishing, which consists in washing the surfaces to be polished with a jet of working fluid mixed with an abrasive and fed under a pressure of 2-3 atmospheres, has recently been coming into use to improve the quality and reduce the roughness of the race and ball surfaces. During hydropolishing, scratches, scale, and other surface defects are not glossed over as they are in mechanical polishing, and defects of the metal are brought out.

The weakest link in high-speed ball bearings is the separator, which, during rotation, is subject to alternating stresses from the

loads and centrifugal forces; these give rise to tensions in its material. The receptacles wear as a result of sliding friction of the balls on the separator; the bridge pieces between the receptacles of the separator are frequently broken due to the severe alternating-load cycle.

Although the chiffon-based textolite separator, which performs satisfactorily up to 30,000 rpm, was until recently regarded as the best separator for use in high-speed ball bearings, it does not deliver the necessary service life at 60,000 rpm. Ball bearings designed for operation at such speeds have nylon separators, which possess a low coefficient of friction and high wear resistance.

It follows from the above that the precision and stability of gyroscope readings and the service lives of the instrument depend on the precision, service life, and operating stability of their gyromotors, the quality of which depends in turn on:

– the quality with which the components and units of the gyromotors are fabricated and their material;

– the quality of the initial material and the standards to which the ball bearings are manufactured;

– the precision of static and dynamic balancing of the rotors;

– the quality of the bearing mounts in the supports and the precision with which the gyromotors are assembled and checked;

– the quality and amount of lubricant applied to the ball bearings.

It follows from the basic factors listed above as influencing the quality of gyromotors that the precision and stability of their operation and their service lives will depend on proper solution of production problems.

Below we present a description of the production processes used

in fabricating the basic components and units, checking them, balancing the rotors, assembling and testing miniature gyromotors to deliver precision, stable readings, and the necessary service life in various types of gyroscopic instruments.

Manuscript Page No.	[List of Transliterated Symbols]
20	ГОСТ = GOST = Gosudarstvennyy obshchesoyuznyy standart = = All-Union State Standard

Chapter 2

CASTING OF GYROMOTOR COMPONENTS

§3. GENERAL

Design Features of Gyromotor Housings and Covers

In modern gyromotors, the housings and covers in combination form the gyromotor housing, in which the rotating rotor and the rigidly secured stator are mounted on supports. In addition, the housing and cover together serve to mount the gyromotor in the outer gimbal ring for the instrument housing. The design and configuration of gyromotor housings are determined basically by the design of the rotor and the mounting of the gyromotor in the instrument itself.

Gyromotor housings and covers must satisfy the following basic specifications:

-they must have minimum outside dimensions and low weight;

-they must provide for secure mounting of the rotating elements of the gyromotor;

-they must possess elastic properties and not undergo dimensional changes during operation;

-their material must have low porosity and resist corrosion in humid atmospheres.

The specifications enumerated above are met by housings and covers having cylindrical shapes and made by casting from alloys based on aluminum and magnesium. The most highly perfected way of making housing and cover blanks for gyromotors in series production

is pressure casting.

The alloy from which the housings and covers of gyromotors are made must have low specific gravity and possess high resistance to corrosion. As a result of the fact that gyromotor housings and covers must be thin-walled, this alloy must also possess high founding properties that enable us to produce solid castings of the required configuration, and must be characterized by excellent mechanical properties to permit machining to obtain low surface roughness and a strong, clean thread. Machining should not encounter difficulties due to pores and blowholes, which are particularly undesirable in thread cutting with cutters and taps.

The alloy must possess elastic properties and not cause deterioration of the gyroscope's operating precision on temperature changes, g-forces acting on the instrument's base, and vibrations of the instrument.

There exists several aluminum and magnesium casting alloys from which component blanks can be poured under pressure. Type AL2 alloy (GOST 2685-53) has come into most extensive use. The chemical properties of this alloy and its mechanical indices are listed in Tables 3 and 4.

The mechanical properties of the castings must correspond to the data listed in Table 4.

The impurities listed in Table 3 influence the alloy in different ways.

A silicon impurity is detrimental to casting properties, raising the fluidity of the alloy. An iron impurity depresses the mechanical properties of the castings, increases brittleness, causes shrinkage cracks, and reduces the tendency to weld to the mold. Copper promotes welding of the alloy to the mold, but causes more

TABLE 3

Chemical Composition of AL2 Alloy

1 Основные компоненты, %		2 Примеси не более, %				
3 кремний	4 алюминий	5 железо	6 медь	7 цинк	8 марганец	9 всего
10—13	10 Остальное	1,5	0,8	0,3	0,5	2,8

1)Basic components, %; 2) impurities not above (%); 3) silicon; 4) aluminum 5) iron; 6) copper; 7) zinc; 8) manganese; 9) total; 10) remainder.

TABLE 4

Mechanical Properties of AL2 Alloy

1 Предел прочности при растяжении, кГ/мм² не менее	2 Относительное удлинение, % не менее	3 Твердость по Бринеллю при диаметре шарика 10 мм и нагрузке 1000 кГ (факультативно)
16	2	50

1) Ultimate tensile strength, kgf/mm^2 not below; 2) relative elongation, %, not below; 3) Brinell hardness with all diameter of 10 mm and 1000 - kgf (optional) load.

rapid corrosion of components cast from it on exposure to sea-water vapor. For instruments designed for operation under marine conditions, the copper impurities in the alloy should be no more than 0.3%.

AL2 alloy possesses superior casting properties among the aluminum alloys as a result of the large amount of eutectic, which promotes formation of castings without cracks at points of transition from one section to another.

The initial materials used in preparing a charge of this alloy are primary pig silumins of types SIL-2, SIL-1 and SIL-0 (GOST 1521-50) and remelted scrap or secondary silumin. The charge is composed of 60 - 40% of pig silumin and 40 - 60% of scrap. It is melted in Type PK-40 smelting furnaces or Type SAT crucibles, with the pig

silumin put in first and followed by the scrap. After each charge of the alloy has been melted, it is cleared of oxide films, slag, and other dirt with a special iron scraper coated with a special paint consisting of 75 – 80 g of zinc oxide and 40 cm^3 of water glass diluted in one liter of water. After painting, the scraper is heated to 200 – 300°. When the entire charge has melted in the melting furnace, the alloy is heated to a temperature of 650 – 700°, once again cleared of slag, oxides and other contamination, and transferred with special ladles into electric or gas furnaces with graphite crucibles.

In view of the fact that aluminum alloys and AL2 alloy in particular tend to become saturated with gases, it is necessary to degasify the alloy during the work; this is done by treatment with chlorides or bubbling with chlorine or nitrogen.

At some of the instrument-building plants, a general-purpose flux is used to purify the molten alloy of gases and oxides and to refine the structure and elevate the mechanical properties of the alloy; this flux makes it possible to refine and modify the alloy simultaneously. The flux consists of a mixture of salts: creolite, the basic refining agent; sodium fluoride, a modifier whose presence, apart from its modifying effect, raises the effectiveness of the creolite; sodium chloride and potassium chloride, which lower the melting point of the salt melt. The universal flux may be used in powered or liquid form directly in the distributing crucibles. Degasification and modification of the alloy are carried out as a single operation in the course of 1 – 3 minutes. Chloride degasification is effected by placing a measured amount of the salt in a stainless-steel bell (perforated container). The bell is immersed in the molten alloy and moved about in the crucible until the metal stops

bubbling; then the surface of the alloy is cleared of slag with the scraper.

Use of the universal flux, the chlorides and the chlorine gas to degasify the alloy requires excellent hood ventilation, since the chlorine and chlorine compounds that are evolved have detremental effects on the health of the workers.

The safest method, but a less effective one, is dry-nitrogen degasification. The essential features of this process are as follows. Dry nitrogen is passed into the alloy in the distributing crucible or smelting furnace when it is at temperature 50 to 80° above the casting temperature but not below 650°; this gas passes from the bottle 1 (Fig. 11) past the pressure reducer 2 and through the dryer 3; from here it goes through the rubber hose 4 to a porcelain or steel tube 5 immersed in the molten alloy (its end should be 100 – 150 mm from the bottom of the crucible).

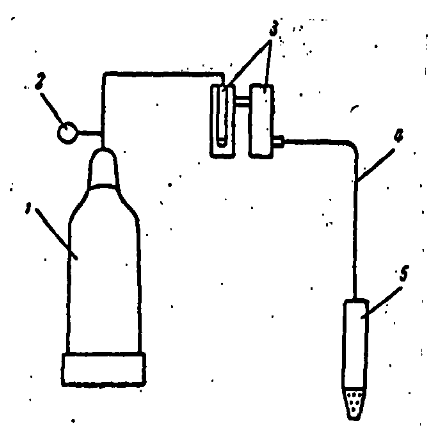


Fig. 11. Apparatus for degasifying alloy with nitrogen.

The reducer valve is opened and the gas feed increased before the surface of the alloy begins to bump,* without formation of bubbles. The tube is moved about in the alloy in such a way that the nitrogen will gradually permeat the entire mass. Nitrogen bubbling is continued for 8 – 12 min, after which the nitrogen is shut off, the reducer valve closed, and the alloy surface thoroughly cleared of slag and oxide films with the scraper.

Chlorine degasification of the alloy is carried out by the same method.

Graphite crucibles are employed in the distribution furnaces, where the alloy stands in the molten state for up to 8 hours. When iron or special steel crucibles are employed, the alloy is usually saturated with iron, which is detrimental to the mechanical properties of the castings. To reduce iron saturation of the alloy during smelting in SAT furnaces with steel crucibles, it is necessary to brush a thin layer of paint on to the inside surface of the crucibles; this consists of 6 parts of quartz sand, 3 parts of fireclay and 1 part of water glass. The ladles used to transfer the molten alloy from the smelting furnaces to the distributing furnaces and the ladels used to pour the alloy into the molds must be painted and baked. The paint recipe and the technique used in painting the ladles may be the same as in the case of the scrappers.

§4. CASTING HOUSINGS AND COVERS BY PRESSURE CASTING

Pressure casting is the most productive method of manufacture for gyromotor housing and cover blanks. Castings produced under pressure have excellent mechanical properties and minimal allowances for subsequent machining. The surface roughness of the castings lies within Classes 5 and 6 (GOST 2789-59). The precision of the castings depends on the precision with which molds were made and particularly on the relative positioning of their moving and fixed parts. All necessary stiffening ribs, lugs, and rough holes, including those for the ball bearings, are produced in the casting blanks for the housings and covers.

The housings and covers are poured on hydraulic casting machines with cold forming chambers, the latter usually positioned horizontally. The basic factors influencing the quality of the castings on machines of these types are the specific pressure on the metal during press-forming, the rate at which the mold is filled with alloy, and the

temperature of the alloy and the mold.

The specific pressure is usually adjusted in accordance with the thickness and configuration of the component to be cast. If the pressure is inadequate, the castings may contain unfilled zones and their mechanical properties will be lowered. An increase in the specific pressure to 380 kgf/cm^2 assists in raising the ultimate strength and relative elongation of the casting materials. At specific pressures of 380 to 650 kgf/cm^2, the ultimate strength and relative elongation show virtually no variation. As the pressure rose between 750 and 1000 kgf/cm^2, the relative elongation and ultimate strength drop sharply (by 20 – 30%). Use of a specific pressure of about 250 – 350 kgf/cm^2 is recommended for the housing and cover castings of most gyromotors, as is the case for thin-walled castings.

The pressforming speed, which is determined by the rate at which the pressurizing piston moves, influences the rate at which the mold is filled with alloy. The higher the pressing speed, the more rapidly will the mold be filled, and the better will be the shaping of thin walls and those farthest removed from the gate. In establishing the pressforming speed, it is necessary to remember that air trapped in the mold is expelled by the alloy and may not have time at high pressing speeds to escape through the channels made for this purpose, so that the resulting castings have increased porosity.

Prior to casting, the temperature of the alloy is established for each component as a function of its configuration and wall thickness, and adjusted at the lowest level that still ensures good filling of the mold. The alloy temperature is set between 600 and 650° for casting housing and cover blanks for the majority of gyromotors.

Raising the temperature of the alloy in casting results in rapid wear of the mold, contributes to spattering of the alloy and formation

of a larger flash, increases the porosity of the castings, raises the oxide content in the alloy, and raises the rejection rate for cracks and other defects.

When the alloy temperature is too low and it has a gruelly consistency, the components may not be poured tight.

The temperature of the mold is also of great importance in pressure casting. It is recommended that the mold temperature be held between 120 and 180° to produce high-quality castings. At higher mold temperatures, the porosity of the castings is increased and mold wear is more rapid. The mold is heated to the recommended temperature prior to casting with a blowtorch. In ecceptional cases, the mold is heated by test castings, but this method usually results in microscopic cracking on the surface of the mold; on expansion, these cracks produce chipping of the metal at various points in the mold.

During work, the molds gradually become heated above the recommended temperatures. Their heating rate depends on the volume and temperature of the alloy being poured. Cooling of the molds is recommended to prevent overheating; for this purpose, special channels are made in them for circulation of cold water.

The AL2 alloy used for casting gyromotor components tends to weld to the mold. Iron, zinc and other impurities present in the alloy reduce this sticking tendency to some degree. Raising the temperature of the alloy and the mold promotes welding. As a rule, welding is observed for the most part in the feed zone, where the temperature of the alloy rises because of the sharp pressure increase as it passes through the narrow section. Welding also takes place on zones where the jet of hot alloy strikes the mold walls directly. To eliminate welding-on, it is recommended that the working surfaces of the mold be smeared with special lubricants. It is necessary to remember that gases

are liberated on combustion of the lubricant and increase the gas porosity of the castings. This is why a thin layer of lubricant should be applied only on those parts of the mold where welding-on is observed. A lubricant of the following composition has been used successfully:

graphite	34%
wax	33%
cosmoline	33%

§5. MOLD DESIGNS FOR PRESSURE CASTING

Gyromotor components are cast on pressure casting machines with horizontal or vertical working cylinders. The molten alloy (in either type of machine) is ladled into a container and pressed by a piston through a gate into a mold whose fixed part is tightly applied to the pouring gate of the machine. The mold for either type of machine consists of two parts — a moving part and a fixed part. The fixed part of the mold is secured tightly to the plate of the machine in such a way that the sprues in the machine container will coincide with the gates in the mold. The moving parts of the mold are secured to the moving plate of the machine. The moving and fixed parts of the mold and, indeed, the entire mold with ejectors must set straight on the machine, with the various parts in proper alignment. In the installation, it is necessary to take the possible heating of the mold into account, since this causes expansion of its components.

In developing a mold design for pressure casting, it is necessary to provide for formation of high-quality castings, maximum productivity, minimum cost, convenient operating conditions, and the possibility of easy repairs.

The troubles that do arise are due, in the majority of cases, to improper design of the mold or incorrect use of it. These malfunctions include, for example, penetration of the alloy into the gaps between

the moving parts of the mold and scratches on the casting surfaces. The latter are due to the absence of the proper casting draws. The casting draws recommended for outside surfaces are 0.5 to 1%, and those for inside are 1 to 1.5% of the corresponding dimension on the casting. The draws are made smaller for machines with vertical chambers than for machines with horizontal chambers. Trouble due to welding of the alloy on to the mold is due to improper charge, composition and to inadequate hardness of the mold surfaces that shape the casting or to their overheating during operation. Further, welding-on of the alloy may also take place due to inadequate cleanliness or improperly selected design of the gating system.

The availability of effective cooling for the mold raises productivity, reduces the rejection rate, and facilitates operation with the mold, since when it is held at normal temperature the alloy is not poured into the gap and the moving parts of the mold score. The tolerances on the moving and fixed components of the mold must be selected in such a way that the mold can be knocked apart when hot, and so that alloy will not pour into the clearance between the fixed and moving components.

The gating device is of great importance. As a rule, the gates must be placed in the mold in such a way that the alloy will flow into them smoothly, without surges; the principle of flat gates with thoroughly polished surfaces conforms to this requirement. The thickness of the infeed-channel section is made 0.15 – 1.5 mm in accordance with the type of casting so that the alloy will fill the form at a rate at which air can escape from the mold cavity and not be trapped by the alloy to form blowholes in the castings. With castings requiring deep zones in the mold, it is necessary to arrange traps into which the first portion of alloy can escape together with the foam, oxides, and

air that has remained in the mold. Usually, the elongated part on the casting that results from the use of this reservoir is used in machining as an artifical reference base; the excess of metal is cut off in the final operations.

Molds for pressure casting are complicated and expensive tools that require large labor outlays. In designing them, therefore, our basic attention should be devoted to normalizing and standardizing individual components and units. The blocks and pedestals, which consist of bases and spacers and are used to secure the moving parts of the mold and eject the castings should also be standardized. The mold-block blanks, in which the working cavity of the casting is situated and which are secured into the general-purpose block, are also usually classified among the general-purpose mold units. The form blocks consist of a movable core and a fixed insert with locating pins that ensure precise positioning of the mold block in the general-purpose block.

The use of general-purpose blocks and fixtures in molds for pressure casting, not to mention standard bolts, bushings and other components, reduces the labor cost of designing and fabricating a mold considerably. It becomes economically feasible to use pressure casting even in short-run production of gyromotors. The job of designing a mold for the use of mold blocks consists in inscribing the configuration of the necessary casting into a pattern drawing of the mold block and making the special parts for fabricating it. Molds for pressure casting of housings and covers for almost all gyromotor designs offer the possibility of using general-purpose fixtures, blocks, and elements in such a way way that either a housing or a cover can be cast simply by replacing only the mold blocks.

Figure 12 shows one of these molds for pressure casting gyromotor

covers on a casting machine with a horizontal piston. Quick design methods using general-purpose fixtures, components and blocks were used in designing the mold.

The mold consists of a fixed plate 11 into which the insert 12 is secured and located with a special pin that ensures precision positioning. The moving core 6 (which is sometimes known as a punch), through which the ejectors 5 and 10 pass, is mounted in the moving plate 9, which is rigidly connected to the plate 7. The plates 4 and 2 are part of the ejection mechanism, which incorporates the eight ejectors 5, which are arranged around the circumference of the cover rim, and the four ejectors 10, which are arrayed around the internal ball-bearing boss of the cover. The large number of ejectors provides for removal of the thin openwork casting that is the gyromotor cover without noticeable deformation. The plates 4 and 2 are bolted together,

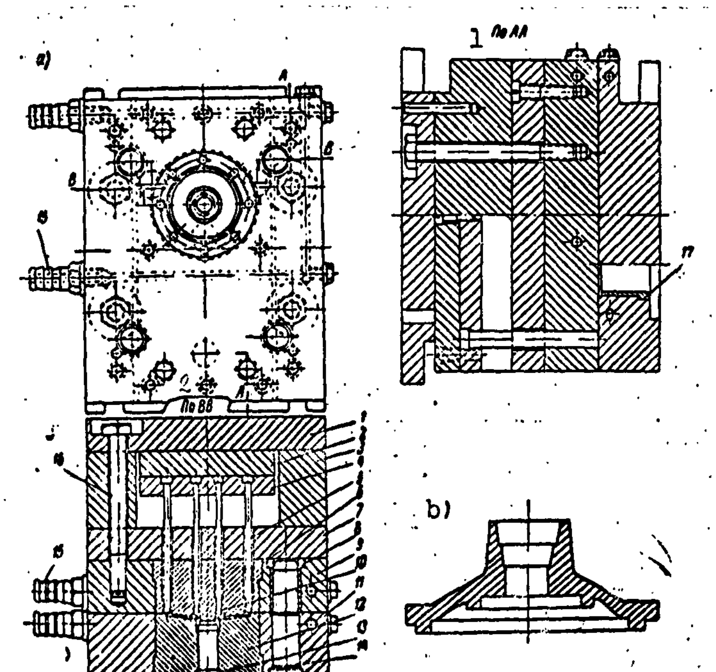


Fig. 12. Mold for pressure casting of gyromotor cover (a). Cast cover (b). 1) Section through AA; 2) section through BB.

and this simultaneously secures the ejectors 5 and 10. The plate 1 carries a movable core which is pressed into it on pins; the latter provide for precision orientation of the core relative to the plates 7, 4 and 2. **The entire system is mounted and secured to the moving** plate of the machine; the spacer 3, through which the bolts 16 pass to secure all plates of the mold's moving element, is placed between plates 1 and 7. The bushings 8, which are press-fitted into the plate 9, and the columns 14, which are mounted in plates 11, guide the moving part and locate it when the mold is closed. The core 13 serves to pour the hole in the cover for the ball-bearing recess.

The liner 17, which connects the machine's compression chamber with the casting cavity that shapes the cover casting, is pressed into a special bore in the plate 11. To cool the mold, special channels are made in the fixed plate and water is fed into them from the main through the connecting pieces 15. Cold water is directed into one of the connecting pieces; passing through the channels in the mold, the water exits from the other connecting piece and cools the mold to the required temperature.

The mold described above consists of a general-purpose block with plates containing sockets for installation of mold blocks in them, the ejection-mechanism plates, which are secured to the moving plate of the machine, and the mold unit, which consists of the core, insert and set of ejectors with plate that form the cover casting. If necessary, the mold block can easily be taken down from the general-purpose block and replaced by a mold unit for another component.

Figure 13 shows the mold block for the housing of one of the gyromotors, which can easily be installed in the general-purpose fixtures described above and the block that replaces the mold unit

for the gyromotor cover. The mold block consists of the upper shaping insert 1, which is mounted in the fixed plate of the general-purpose block, and the internal shaping core 2, which is mounted in the moving plate. The core 4, which shapes the boss and the hole for the ball-bearing receptacle in the housing, is pressed into the insert. The plate 3 carries the central ejector 5, which pushes the housing in the ball-bearing boss, and the eight ejectors 6, which are arranged around the housing's circumference. The ejector plate can be made either square or circular.

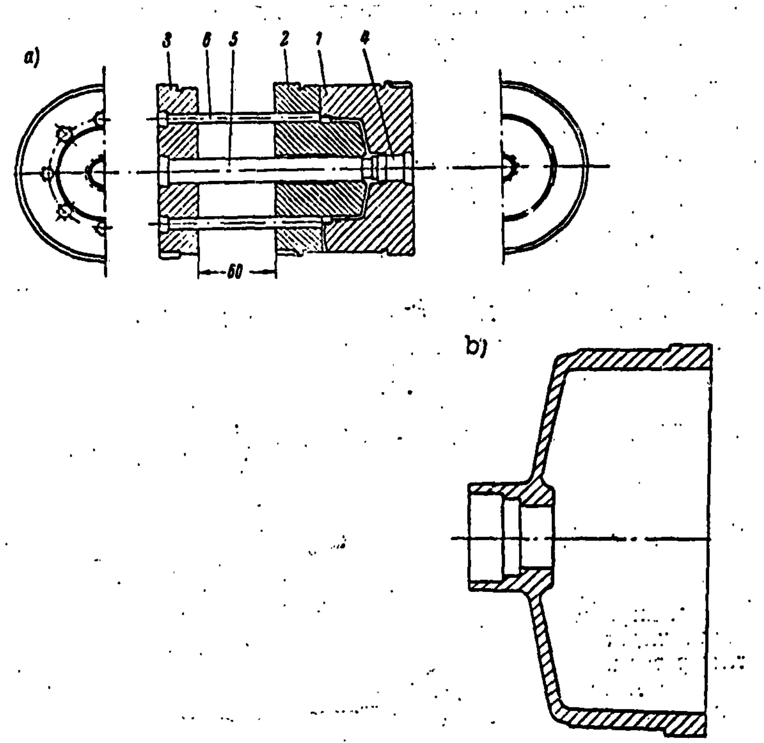


Fig. 13. Mold block for gyromotor housing (a). Cast housing (b).

The components of the general-purpose block are made from steels of the following types: steel 10 for all plates of the molds; steel U7A for the columns, guide bushings and locating pins; steel 50 with subsequent heat treatment for the ejectors. The liners, the mold-

block cores, and the gating bushings, which come into direct contact with the molten metal, are fabricated from a steel possessing high mechanical properties at high temperature and a small coefficient of thermal expansion so that constancy of the casting dimensions is guaranteed. The steel must also be corrosion- and erosion-resistant and possess high resistance to thermal fatigue. Type 3Kh2V8 steel, from which the cores and inserts for cast gyromotor housing and cover blanks are fabricated, satisfies these specifications.

Casting of housings and covers is done as follows in molds on machines with horizontal pistons. At the initial point in time, the machine's moving plate, carrying the moving part of the mold, is in tight contact with the fixed part of the mold and the fixed plate; thus, the mold is closed. Then the amount of molten alloy specified for the casting in question is poured into the gate of the machine with a ladle. Pressing the "start" button turns on an electric motor that is coupled to a centrifugal hydraulic pump; this pumps oil into the cylinder of the machine's piston. When a special footpedal is pressed, the piston begins its stroke and at a certain pressure, expels the molten alloy into the mold cavity from the container and gate bushing through the gate. After the casting has solidified in the mold (the solidification time is selected in practice for each casting), the founder presses a button to retract the machine's moving plate with the moving part of the mold and opens the mold. Together with the gate, the cast blank is pulled out of the fixed mold element and continues its motion with the moving part of the mold. As soon as the casting has cleared the fixed insert completely, the plate 9 comes to rest against special stops on the machine and the entire mechanism for ejecting the casting, which consists of the ejector 5 and 3 and plates 8 and 9, which are connected together,

comes to a stop, while the moving insert continues its motion together with plates 6, 7 and 10 with the moving plate of the machine. As the motion continues, the casting is removed by the ejectors, the core and insert are cleared of casting residues and lubricated if necessary; then the button is pressed again to bring the machine's moving plate with the moving part of the mold mounted on it back into contact with the fixed part, thus preparing the machine for the next casting cycle.

§6. CASTING DEFECTS AND OPERATION OF MOLDS

In pressure casting, the basic defects that lead to rejection must be taken into account when the mold is being designed. All reject-producing factors that depend on mold design must be definitely eliminated in finishing the mold, before it is turned over for use. Thus, rejects can occur only in the event of deviations from correct production procedure or when the molds are improperly used.

The basic defects of pressure castings are gas blowholes and porosity. The most typical form of porosity reject is air porosity in the form of a fine granular material around the center of the casting, or in the form large blowholes in expanded parts of it. Air porosity in the castings is a result of air becoming trapped by the molten alloy as the mold fills. Apart from improper positioning of the gate or improper gate shape, air is trapped filling the mold with alloy and at an excessively high rate. With high pressing speeds, there is not time for enough of the air to escape from the mold cavity through the relief channels. The pressing speed adopted for each mold must guarantee formation of high-quality castings.

As a rule, gas porosity near the surfaces of castings is due to the presence of excessive lubricant. The unburned lubricant evolves gases which enter the outer layers of the casting during the decantation process. It is necessary to use the minimum of lubricant, applying

a thin layer only to those places to which the alloy tends to adhere. Casting must not be carried out if gases are being evolved. Foreign inclusions in the interior of the castings (slag, aluminum oxide films, graphite) are the result of substandard content of the alloy in the distributing furnaces or incomplete refining of the alloy. To prevent foreign inclusions from getting into the castings, it is necessary to let the alloy stand in the crucible after degasification, not to agitate it during casting, and not ladle from the bottom.

Apart from internal defects in the castings due to improper technology in preparing the alloy and operating the machine, we frequently observe surface flaws that are usually functions of the proficiency with which the mold is used. To eliminate surface defects from the castings and to increase the service lives of the molds, it is necessary to blow compressed air through the mold before beginning work in order eliminate foreign particles, dust, and flash residues, which would inevitably get into the casting and the joints in the mold, causing damage to the moving parts.

One of the most common forms of reject in pressure casting is scoring on the surfaces of the products due to adhesion of the alloy to the mold components. The cause of the adhesion is the erosive action of the alloy jet and its chemical interaction with the mold metal. Severe adhesion of the alloy takes place when the alloy temperature is too high and when the mold components become overheated, particularly those components which are directly exposed to the stream of hot alloy. Excessive hardness in the mold working surfaces also contributes to adhesion of the alloy. Lubricating the mold with special lubricants reduces alloy adhesion.

Another form of surface reject is patterning on the surface of the casting. It is caused by pouring hot alloy into an inadequately heated

mold, low pressing speeds, and constricted gate sections, in which case the alloy entering the mold cavity is pulverized to form a fine spray pattern.

There are a number of other causes for rejection and methods for eliminating them; these are described in the specialized literature.

§7. CENTRIFUGAL CASTING OF SHUNT-TYPE ROTOR WINDING

In centrifugal casting, the molten metal is poured into a rotating mold and distributed around the mold's internal surface by centrifugal force. The metal chills, filling the cavity of the mold.

The metallic alloy poured into the casting mold is regarded as a nonhomogeneous fluid consisting of particles of the metallic mass, which has the highest specific gravity, slag particles with lower specific gravity and, finally, gas bubbles of the lowest specific gravity.

The castings produced from such a nonhomogeneous fluid are also nonhomogeneous, irrespective of the casting technique. The nonuniformity of castings produced by pressure-, chill-mold, and sand-casting arises as a result of capture of gases, oxides, slag and other impurities in the molten metal. In the molten metal, which is in a state of rest in the crucible, particles with low specific gravity float to the top, while particles with higher specific gravity sink. As the lighter components, the gases, oxides and slag collect toward the top of the casting in sand- and chill-mold casting; the heavier metallic particles collect at the bottom. In the pressure-casting process, particles of different specific gravities become mixed, and gaseous and slag inclusions are found in all parts of the casting.

Nonuniformity is not admissible in certain forms of casting, such as the shunt-type rotor windings of precision gyromotors, since nonuniformity of the metal lowers the conductivity of the winding and

this, in turn, reduces the rotor speed below the specified level. The centrifugal casting method is used to obtain a dense, uniform, impurity-free shunt-type rotor winding from pure aluminum.

As the molten metal spins in the mold, gaseous and slag particles, which have lower specific gravities, will accumulate near the casting's axis of rotation, while the metallic particles with their higher specific gravities will tend to collect at the outer surface of the casting. By increasing the rotory speed of the mold, we may vary the pressure on the particles at will over a wide range and guarantee dense uniform castings.

Shunt-wound-type gyromotor rotor windings are produced by pouring the bars into slots in the iron. After casting, these bars are integral with the two connecting rings situated on the faces of the rotor. In precision high-speed gyromotors, the shunt winding is cast from pure aluminum, which guarantees excellent conductivity. There are gyromotors in which shunt-type windings are cast from AL2 alloy.

The process of casting a shunt-type rotor winding from pure aluminum for a miniature gyromotor is extremely complex. Centrifugal casting methods are employed to produce a dense, homogeneous structure in the bars and connecting rings of the winding. The procedure of the casting process, the metal and mold temperatures, the speed of the machine's spindle, the rate of pouring, the ladle capacity, and other factors are established on experimental runs of the gyromotors. The rate at which the mold rotates exerts an essential influence on the quality of the cast shunt-type windings. There are formulas available for determining the necessary mold rpm's; these are used to obtain a tentative figure which is later refined.

It has been established in practice that a shunt-type winding with an inside rotor-iron diameter of 30 mm can be cast at a low

TABLE 5

Chemical Composition of Aluminum

1 Марка	2 Алюминий, %	3 Примесей не более, %				
		4 железо	5 кремний	6 сумма, железо и кремний	7 медь	8 всего
A2	99,0	0,5	0,5	0,9	0,02	1,0
A1	99,0	0,3	0,17	0,45	—	—

1) Type; 2) aluminum, %; 3) impurities not above, %; 4) iron; 5) silicon; 6) iron plus silicon; 7) copper; 8) total.

speed of 3000 rpm to satisfy electrical and mechanical specifications.

Aluminum with a high electrical conductivity and a chemical composition conforming to GOST 3549-55 (see Table 5) is used for shunt-type windings in order to assure the specified electrical parameters in precision high-speed gyromotors, as we noted above. The conductivity is not to exceed 32 m/ohms·mm^2 for type A1 aluminum or 29 m/ohms·mm^2 for A2. After the shunt-type winding has been cast, however, the conductivity of the aluminum in the bars and rings of the winding diminishes. This decline takes place basically because of the increased silicon and iron impurities in the aluminum of the winding. The drop in conductivity due to the impurities may be computed roughly but with sufficient accuracy by the following formulas for iron and silicon, respectively:

$$\text{for iron} \quad \Delta\% = \frac{100n\%}{32}, \qquad (2)$$

$$\text{for silicon} \quad \Delta\% = \frac{700n\%}{32}, \qquad (3)$$

where Δ% is the drop in conductivity in % and $\underline{n}$ is the content of the iron or silicon impurity in the aluminum, in %.

An increase in the amount of impurities that reduce the conductivity of aluminum in the casting process of shunt-type rotor windings takes place due to the increase in the iron impurity in the aluminum

during the latter's smelting process and contact with the iron package of the rotor, and as a result of formation of an oxide film in the smelting process, this film remaining in the shunt-type winding in the form of small inclusions.

The iron-impurity content in cast shunt-type windings increases due to the presence of flashes in the slots; when the slots are filled with molten aluminum, these melt, so that there are more impurities in the bars than in the rings of the winding. Further, the aluminum becomes saturated with iron as a result of the use of iron or steel crucibles and pouring ladles that are not properly painted with special paints. For this reason, it is necessary to use graphite crucibles in the smelting and distributing furnaces. There should be no flashes or metal dust in the slots and end sheets of the rotor's iron. The pouring operation must be completed in the specified number of seconds. The pouring ladles must be carefully painted and baked and have the definite capacity specified for each type of gyromotor. Use of ladles having a different capacity may cause underfilling or high saturation of the aluminum with iron.

At one of the plants, as many as 50% of the gyromotors in certin consignments made in a production process that had already been highly developed had to be rejected because of substandard speeds. It was established on analysis that the iron content in the winding aluminum of the rejected gyromotors was considerably higher than in the aluminum of gyromotors from the same consignment that developed the normal rpm's. On careful checking of the execution of all operations in fabrication of subsequent consignments in strict accordance with the production regime, it was found that one of the founders was using a casting ladle for gyromotors of one type in casting the shunt-type rotor winding for another type of gyromotor;

the capacity of this ladle was over twice as large. The founder used the contents of the ladle to cast two windings, placing it in the distributing furnace after pouring the first rotors so that the aluminum would not chill. The aluminum remained in the ladle during the entire time necessary for removing the mold from the machine and replacing it and inserting the rotor's iron packet into the mold. Waiting in the iron ladle, the molten aluminum became saturated with iron and the cast winding had inadequate conductivity which ultimately led to rejection of the gyromotors because of the substandard speeds that they developed. The speed of the gyromotors using the rotors cast from the first part of the aluminum met technical specifications. Even such a minor deviation from procedure resulted in a considerable loss to the plant (the rotors were finally scrapped).

An aluminum oxide crust always forms on the surface when aluminum is smelted in crucibles. The specific gravities of the oxide film and aluminum are almost identical, so that it is difficult to tap off the film from the molten aluminum during degasification.

If the surface of the molten metal is not watched, the film will be broken up when the metal is picked up by the ladle and will enter the shunt-rotor casting together with the aluminum in the form of fine inclusions, thus reducing the conductivity of the aluminum. To protect the molten aluminum from the outside film, it is necessary to clear its surface at intervals with a special scraper having a heat-insulating coat of paint.

The charge for pouring shunt-type gyromotor rotor windings is prepared from aluminum that has first been remelted in graphite crucibles. During casting, the temperature must be held between 780 and 820°. During melting, the crucible must be closed.

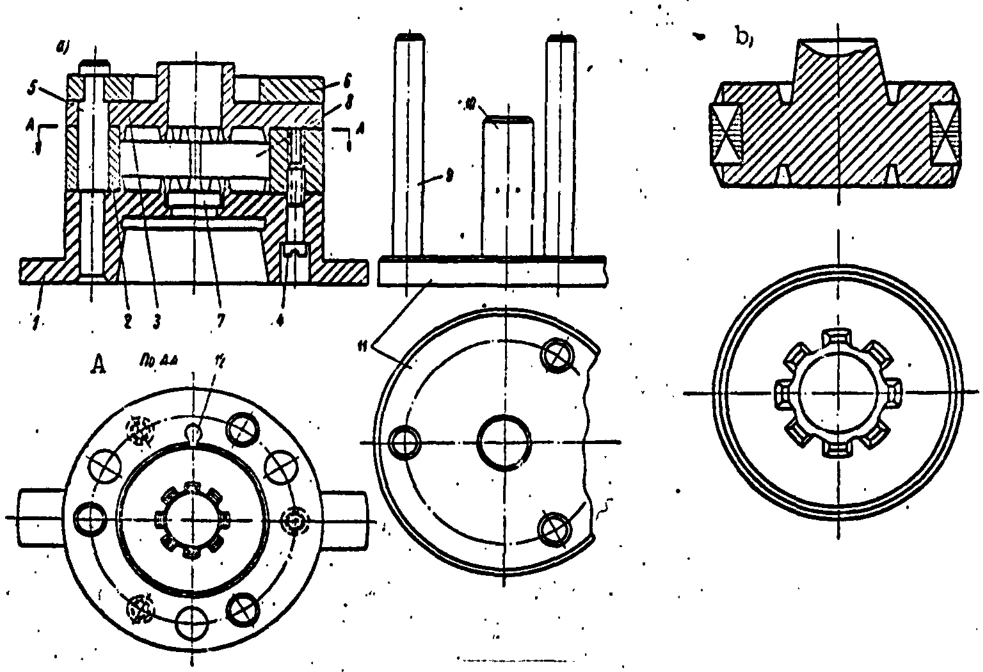


Fig. 14. Centrifugal casting mold for shunt rotor winding (a). Invested iron packaged with shunt winding (b). A) Section through AA.

Shunt-type rotor windings for the gyromotors are cast on special vertical-axis centrifugal machines in special molds. One such mold is shown in Fig. 14. The mold consists of a base 1 to which a special ring 2 is secured with the three bolts 4. The mold cover 3, which has a central hole and three holes for pressing out the casting, is seated by its holes on the columns 5. The cover acts simultaneously as the mold gate and the upper half of the mold which shapes the shunted ring of the winding. The lock ring 6 is pressed on over the cover and the columns. The three columns inserted in the base 1 and passing through the ring 2 have special necks at the top. When the mold is locked, the ring presses on the cover, pressing on the rotor-iron package from the top with its lugs, and pushes it against the base 1, fitting into the column necks with its three eccentric circumferential holes. A special insert 7 with eight projections is

pressed into the base from below; the rotor-iron package to be invested is set up on this insert and compressed from the top by the eight projections on the cover. The mold is set up by its tapered bore on the faceplate taper of the centrifugal machine's vertical spindle and secured to it with a locking device. For this purpose, the faceplate of the machine spindle has recesses into which the two lugs on the base 1 of the mold fit. The mold is secured with a special key inserted into the slots of the ring 6; when the key is turned, slots on the ring enter those on the locating pins.

A special extractor (Fig. 14a) consisting of the three pins 9 and a central post 10 secured in the base 11 is used to press the invested rotor package from the mold; its pins enter holes in the cover when the casting is stripped.

Before the first rotor package is poured, the mold is heated to a temperature of 100 – 150° and the locking ring 6 is removed from the columns by pulling it out of the column slots with a turn of the key. Then the cover is removed from the base 1 and set up on the bench. The rotor iron package 8 is set up by its outer diameter in the ring 2 in such a way that the teeth of the iron are resting against the special projections on the insert and the iron is located by the positioner 12; this guarantees free passage of a gage of the necessary size into the slots in the iron. A cover with the same type of projections as those in the lower insert is pressed on from the top, coming to rest against the teeth of the rotor iron and the ring 6. The iron package is pressed to the size indicated on the blueprint, after which the key is used to turn the ring 6 through an angle that allows the ring slots to sink into the column slots. Secured in this manner, the mold with the rotor iron package is placed by its tapered bore on the faceplate cone and by its lugs into the faceplate slots of

the centrifugal machine. A special protective frame secured on the machine column is dropped over the mold from the top. Then the electric motor driving the V-belt to the machine-spindle pulley is switched on to set the faceplate and mold in rotation. The aluminum is poured through a funnel mounted on top of the machine's safety frame. The funnel opening coincides with the hole in the mold cover and functions simultaneously as a gate. From the funnel, the metal enters the gate in the cover, passes into the hole in the packet, and, on leaving the packet, fills out the lower shunted ring under the action of the centrifugal force. Rising upward through the slots, the alloy remains in them forming the bars of the winding, and then fills out the upper shunted ring.

After the metal has been poured out from a ladle of the necessary capacity and the funnel into the mold gate, the machine is allowed to spin for another 10 – 15 sec, or until the aluminum has solidified fully. After the machine is stopped, the protective frame is raised and swung away on its column. The locking ring 6 of the mold is turned with the key until the faces of its oval holes come out of the column slots and the projections of the mold base 1 have been pulled out of the faceplate sockets. The mold is lifted from the machine with the casting and set up on a special base on the bench, and the rotor-iron packet with the shunt winding on it pressed out of the mold on the press with the aid of the stripper.

During pouring, the metal must not splash suddenly into the gate, since it will plug the gate and not fill the slots in the iron; nor is it admissible to interrupt the flow of metal.

The ladle capacity should provide metal for only a single casting. Prior to operation and as the paint loosens during operation, the ladle must be repainted with heat-insulating paint.

In the manufacture of certain gyromotors in which the rotor-winding resistance and, consequently, the speed developed vary over a wide range, the shunted winding of the rotor is poured not from aluminum, but from AL2 alloy, using centrifugal machines or pressure-casting machines.

§8. VACUUM PRESSURE CASTING

Despite the measures taken in designing molds for pressure casting and in the casting process itself, the number of gyromotor housing and cover blanks having blowholes after casting is relatively large. Finished housings or covers are sometimes rejected due to blowholes that open during the final machining operations.

The mechanical strength of housings and covers with blowholes is much lower. Since housings and covers must withstand certain deformations, it is important that these components not have air or gas cavities when used in key gyromotors that must operate over a wide temperature range. As we know, gas and shrinkage porosity can be eliminated relatively easily in pressure casting, but the same cannot be said of air porosity due to trapping of air by the metal as the mold is filled. As a consequence, castings produced by the pressure method are always porous to one degree or another. If rigid specifications are set forth as to the density of the castings, we resort to the centrifugal or vacuum-pressure casting method.

Vacuum casting, which is sometimes known as nonferrous-alloy suction casting is widely used for simple castings of the body-of-revolution type that can be fabricated by the methods developed by B.M. Ksenofontov. The bottom of a thin-walled, continuously water-cooled metallic mold known as the crystallizer is immersed to a certain depth in a crucible containing the fused metal. Then the air is evacuated from the top part of the mold by a vacuum pump until

a certain vacuum has been reached. The metal is drawn up into the mold to the specified height, the casting that forms is allowed to solidify and is then ejected. The mold is smeared and again immersed into the metal, and the cycle is repeated.

The resulting castings have a dense, fine-granular structure.

The method described above is used to cast only round castings, from which various types of bushings, rings, nuts, small gears, etc. are machined. It is impossible to produce castings with more complex configurations by this method. The firm Aurora Metal (USA) uses vacuum casting in permanent molds to produce castings with more complex configurations from nonferrous metals. A steel ingot mold is placed inside a hermetically sealed housing having two openings: one communicating a vacuum pump and the other for passage of the connecting piece through which the molten metal enters the mold; during casting, the tube leading to the gate of the mold is lowered into a crucible containing the molten metal. A vacuum is set up inside the housing and the liquid metal fills the mold under atmospheric pressure.

The rate of inflow of the metal is regulated by the difference between atmospheric pressure and the residual pressure in the hermetically sealed housing.

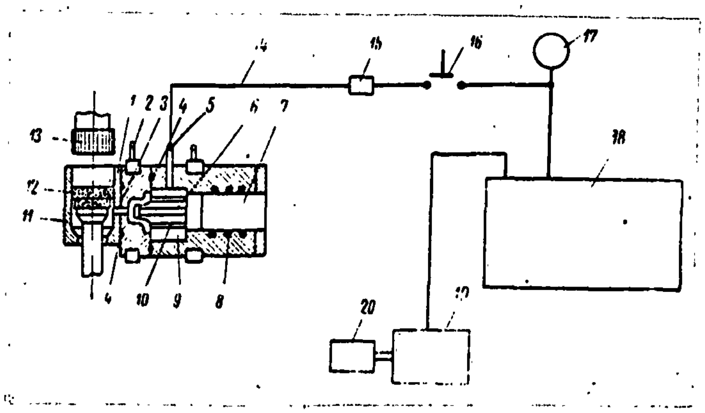


Fig. 15. Diagram of vacuum die casting.

The castings obtained are distinguished by low tolerances and smooth surface. The cast components are produced with a hard skin on the surface, a refined grain and improved physical properties. The possibility of regulating the rate at which the metal enters the mold enables us to produce good castings without bubbles and "draw." Since air is almost completely eliminated from the cavities of the mold, the castings have no blowholes.

Complex-configurated castings can be produced by a combination method of vacuum die casting.

A schematic diagram of the combination vacuum-die-casting procedure is shown in Fig. 15. A special casting die is set up on a hydraulic die-casting machine with a cold vertical glass chamber. The mold differs from the ordinary mold in that the special circular inserts 4 are inserted in grooves in the fixed plate 1 to create an air-tight space within their circumference, at the center of which the casting gate 3 with its cutoff device is situated. When the mold is closed, an annular bead on the movable plate of the mold is pressed against a second spacer in a groove in the face of the fixed body of the mold. This sets up air-tight insulation between the inner chamber and the cavity of the mold. The piston 7 with the ejectors 6 and 10 secured to it is situated in the bore at the back of the movable part of the body. The packing 8, which ensures that the chamber and working cavity of the mold will be air tight, is inserted into special grooves between the piston and the inner wall of the movable body of the mold. The mold chamber 9 is connected with the cavities that shape the casting and with the gate through the clearances between the ejectors and the holes for them in the cores. The fitting 5 is screwed into the body of the mold's movable part from the outside and a rubber hose 14 is pushed on over it to connect the vacuum chamber of the mold with the

air line, the three-way valve 15, the vacuum regulator 16, and the ballast 18. The vacuum in the line is measured with the vacuum gauge 17. The vacuum pump 19 is driven by the electric motor 20. Tap water is supplied through the stub pipes 2 at the joint between the moving and fixed parts of the mold body in order to cool them.

Casting of parts on the vacuumized die-casting machine takes place as follows. When the electric motor is switched on, the vacuum pump evacuates the air from the ballast, creating in it a vacuum that is measured by the vacuum gauge. The three-way valve is in the position in which it blocks communication between the ballast and the inner chamber of the mold. The mold must be closed. The batch of molten metal 12 is poured into the charging cup 11 and a pedal operated to drop the pressing piston 13. The three-way valve opens simultaneously with the descent of the piston; this makes it possible for the air to pass through the air line, with the necessary rarefaction, from the mold chamber to the ballast. Since there was air only in the mold chamber before the three-way valve opened, a low pressure is set up throughout the entire system. The vacuum will depend on the vacuum initially created in the ballast, its volume, and the volume of the airspaces in the mold. To obtain higher vacuums in the working cavities of the mold, it is necessary to increase the initial vacuum in the ballast and use a ballast tank of sufficiently large volume.

The metal is squeezed out under pressure through the gate into the mold cavity, filling it completely. Since there is virtually no air in the gate and mold cavity at the time of pouring (which coincides with opening of the three-way valve), no air will be trapped by the metal as the mold is filled. The three-way valve closes when the mold is opened, thus connecting the mold with the atmosphere. Together with the moving part of the mold, the casting comes out of the

fixed part of the mold cavity, and the piston with the ejectors 5 and 6 comes to a stop against the studs of the machine. The moving part of the mold with the casting continues its motion away from the machine plate until the casting comes up against the ejectors 5 and 6. With further motion of the moving part of the mold, the casting is removed from the mold insert and taken from the machine area. Then the mold is joined and the cycle repeated.

When the molten metal is being pressed from the cup on the machine through the gate into the mold, it encounters air nowhere along its path, and the casting is dense, fine-grained, without air or gas bubbles, and possessed of excellent mechanical properties; this makes it possible to recommend more widespread implementation of the method.

§9. CENTRIFUGAL-VACUUM INVESTMENT CASTING

During recent years, investment casting has come into increasingly widespread use in instrument building. This method is used under the conditions of large-series and short-run production to cast almost all components that cannot be cast by any other method because of precision specifications and the complexity of the design. Use of this method sharply reduces the volume of machining and the amount of metal used. The process under consideration is employed in instrument building for casting parts from magnetic alloys and high-carbon and alloy steels.

The essence of the investment-casting process consists in first preparing from a formable material (modeling cement, plaster of paris, aluminum alloys, plastics) a master model — a prototype of the future casting — differing from it dimensionally by twice the shrinkage (the shrinkage of the wax mixture and the shrinkage of the metal being cast). The master model is used for preparation of a die-casting mold by hot molding from easily formable materials, and it is into this

mold that the prototype component is poured from low-melting modeling compound. Several types of modeling compounds have been developed for various foundry conditions. These compounds, which contain cellulose or polystyrene, melt at temperatures from 110 to 250°, while compounds containing stearin, paraffin or wax melt at 50 to 80°.

To obtain dense, low-shrinkage investment models possessing adequate mechanical strength, the modeling compound is forced into the die-casting mold under pressure on a hydraulic ram. Then the model is dipped in a bath (or sprayed with a spraygun) to cover it with a liquid cementing compound (ethyl, silicate, [sic] water glass). Thus the model becomes coated with a film, which is sprinkled with fine calcined quartz sand. The model is formed in special flasks, by filling the gaps between the painted walls of the model and the flask walls with a special filler. Dry fillers consisting of a mixture of quartz sand with water glass are used in melting steel castings.

After shaping the wax pattern in the flask, the modeling compound is melted out of the mold before casting. Low-melting modeling compounds are melted out with a jet of steam, and high-melting compounds with hot air. The melted-out patterns are dried in electric furnaces and fired after drying. Then the flasks are transferred to the foundry department and set up on the machines. The metal may be poured into the melted-out pattern in the conventional manner, under pressure, under vacuum, or by the centrifugal and composite centrifugal-vacuum methods.

Blanks for gyromotor rotors, whose fabrication is usually attended by time-consuming machining operations and great waste of metal in the chip, may be investment-cast.

At one of the plants, an attempt was made to investment-cast rotors by the conventional precision-casting method. During subsequent

machining of the rotor blanks, large numbers of blowholes and nonuniformity of the metal were detected. This suggests that it will be necessary to use a casting method in which air and gas are eliminated from the mold at the time of casting and measures are taken to produce a uniform and sufficiently dense rotor metal. The presence of blowholes and loose-structured areas in the rotor complicates dynamic balancing and lowers its mechanical strength.

Gas holes can be eliminated in casting of rotor blanks by use of the vacuum method for filling the molds as described above. In this method, elimination of gases is better than that achieved in other methods, but during casting the metal is not purified of various nonmetallic inclusions that usually lower the mechanical properties of the casting. In the centrifugal casting method, the product is of uniform density and clean-surfaced, and the chemical composition of its metal is uniform. However, this does not exclude the possibility of gas holes being present in the casting as a result of incomplete elimination of the gases from the mold.

Thus, neither the vacuum nor the centrifugal method, taken alone, can insure that all casting blanks for the gyromotor rotors will be acceptable. The production of dense, uniform rotor blanks free of blowholes and requiring a minimum of subsequent machining can be guaranteed by the combined centrifugal-vacuum casting technique.

The combination centrifugal-vacuum machine is used for casting rather complex tools from high-alloy steels. Rotor blanks for gyromotors can also be cast on such machines.

Figure 16 shows a diagram of an installation capable of performing combined centrifugal-vacuum casting operations. The outer diameter of the suction tube 1 slides easily inside the hollow shaft 11 of the centrifugal machine. The bottom end of the tube is enclosed in a ver-

tical guide; the upper end of the tube, which passes, together with the shaft, through the rotating shaft of the centrifugal machine 3, extends directly to the bottom of the mold.

The mold shown in the figure was designed for casting the rotor blank 10. The flask 6 is set up on the spacer insert 2 in the socket of ring 4 and pressed into it by the clamps 5 with snap-open locks 7. The same locks press the cover 8, which serves to prevent spattering of the metal as the centrifugal machine rotates. The molded and heated flask is placed on the table of the centrifugal machine. The hole in the downgate is blocked by the special graphite rod 9. After the pouring basin has been filled with the computed quantity of molten metal, the centrifugal machine is started and, when it has reached the required speed, the graphite rod is pulled out, simultaneously opening the three-way valve 15, which communicates through the suction tube via a rubber hose 12 with the ballast 17, from which air is evacuated by cutting in the vacuum pump 18, which is driven by the electric motor 13. The vacuum in the line and ballast is measured by the vacuum gauge 16. The depth of the vacuum is regulated with the valve 14. Under the vacuum, the gas present in the mold cavity has time to escape before the molten metal begins to arrive. The batches

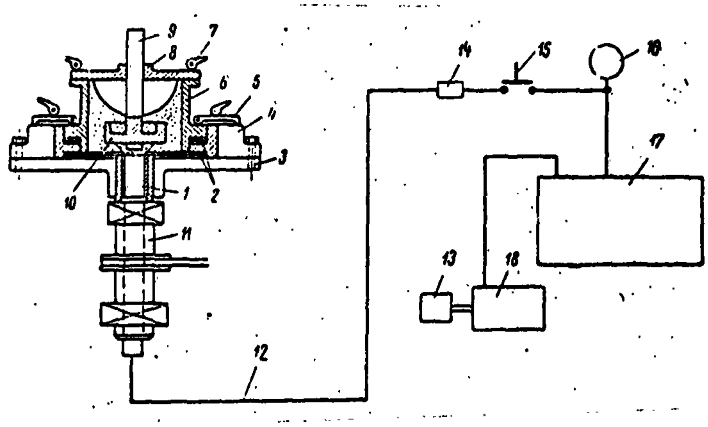


Fig. 16. Diagram of centrifugal-vacuum casting.

of metal must be figured quite closely.

The equipment is rather complex, but the considerable saving of metal and the reduced labor cost may justify the initial outlay.

§10. INSPECTION OF CASTINGS

Gyromotor components cast by any method are gauge-checked and their surface state is determined by visual inspection. The chemical composition, mechanical properties and density of the casting alloy are determined.

Control of Chemical Composition

The chemical compositions of foundry alloys and metals are controlled by the spectral or chemical methods, in which the contents of the basic components and impurities are determined in per cent. In AL2 alloy, the silicon, iron and copper contents are usually determined.

Analyses to determine the chemical compositions of the alloys and metals are conducted by the spectral method at the instrument-building plants.

Due to its sensitivity, quickness and low cost, and to the possibility of analyzing semifinished work pieces and finished products without removal of special specimens, spectral analysis is widely employed in industry as a method for determining the chemical compositions of alloys and metals. One of the merits of spectral analysis is its high sensitivity, which enables us to determine negligible fractional percentages of various elements. The time required to conduct the chemical analyses of the alloys may be reduced to 15-20 minutes; thus, rapid and precision inspection of melts in the foundries becomes possible.

The ISP-22 quartz spectrograph, which conforms to modern requirements, is used to control the chemical compositions of nonferrous metals and alloys by the spectral method. Quantitative and qualitative

analyses of not only nonferrous, but also other metals and alloys, including alloy steels, can be run on the ISP-22 spectrograph.

The chemical composition of the metal or alloy is determined by the spectral method on specimens that have been cast in a special chill mold from the same melt as the gyromotor-component castings to be inspected. If the chemical analysis yields unsatisfactory results, a new test is run on an alloy from the same melt and if the result of this analysis is still unsatisfactory, the consignment of cast components from this melt is rejected or, if the analysis has been run while the pieces were being cast, casting is suspended.

The chemical analysis of AL2 alloy and components cast from it should indicate the percentage contents corresponding to those listed in Table 3, while those of components cast from A2 or A1 aluminum should conform to Table 5.

Control of Mechanical Properties and Dimensions

To determine the mechanical properties of an alloy from which gyromotor components have been cast, six specimens are cast from it in a special chill mold. The shape and dimensions of the cast specimens should correspond to the machine or press on which the test is to be run and also conform to the specifications of GOST 268-53. The number of the melt is punched onto the cylindrical end of the specimen. The test is run with the casting skin. Minor trimming with emery cloth is permitted if there are large flashes on the outside surfaces of the specimens. Mechanical tests are run on the Amsler tensile machine or on a Gagarin press. On the basis of the results obtained from two of the three test specimens, the blank and component castings prepared from this alloy are regarded as acceptable if the test results conform to the requirements as to the mechanical properties of the alloy shown in Table 4. The average value of those obtained on the two specimens

tested is taken as the index to the mechanical properties of the alloy. If the test results for the first free specimens are unsatisfactory, the remaining three specimens are retested, and if the repeated tests also give unsatisfactory results, the entire consignment of components cast from this alloy is rejected.

All casting dimensions of the blanks are checked on the first acceptably cast component, and when the consignment is turned over for acceptance, a certain percentage of it is taken. When deviations from the foundry blueprint dimensions are detected, the entire consignment of cast component blanks must be inspected.

Determining Density of Castings

Of all existing methods for detecting internal defects in castings, the most effective are the x-ray and gamma-ray methods. This fluoroscopy detects cracks, holes, foreign inclusions, seams and other defects without damage to the parts being tested.

Small aluminum-alloy castings are inspected on special x-ray machines of type RUP-1. The "Mosrentgen" plant has mastered the production of new x-ray apparatus for industrial defectoscopy. One of the units, the RUP-60-20-1, is specially designed for inspection of light-alloy castings and molded plastics. The apparatus is mounted on a carriage with a control panel, a generator, and an x-ray tube on a tripod. The apparatus may be used for inspection of aluminum- and magnesium-alloy components up to 100 mm thick and components of other materials. The unit is designed for operation in industrial laboratories and directly in the shops.

The homogeneity and density of the metal are affected by gaseous and slag inclusions, cracks, blowholes and other casting defects. The density and uniformity of the castings are observed directly on the unit's screen during illumination.

In certain cases, x-ray photographs are taken of a section of the casting.

Control of Surface State of Castings

Special technical specifications have been drawn up for acceptance of certain blanks for housings and covers that have been die-cast; these are concerned with the following:

a) the method of determining internal defects (by breaking the specimen or by x-ray illumination);

b) point of break or x-ray illumination;

c) number of castings for determination of internal defects (no more than 3% of a consignment is recommended);

d) defects that influence operational specifications and that cannot be tolerated.

The technical specifications may also include specimens that characterize the quality of the castings.

Cast blanks for housings and covers may not have cracks, draw, misruns, seams and foreign inclusions on their surfaces; ribs and flashes on unmachined surfaces must be cleaned flush. The dimensions of the gate and ejector marks on the surfaces to be machined must be within the machining allowance. Local deteriorations in the form of surface roughness are tolerated on an area no larger than 20% of the casting's entire surface. These include traces of fine cracks in the mold less than 0.2 mm high and marks from the ejectors that penetrate or project by no more than 0.2 mm.

All housings and covers produced are subject to superficial inspection with the unaided eye. Casting defects (depressions, nicks, bubbles) are tolerable if they are within the machining allowance after inspection trimming and the holes do not exceed the size range indicated below. Thus, for example, blowholes encountered in castings

for covers during the machining process must be within the following tolerances.

The inner face of the catch (lock) may have isolated blind bubble holes up to 1.5 mm in diameter or length and up to 0.5 mm deep, in number up to three situated at a distance of at least 5 mm from one another and at least 1 mm from the sharp edges.

The flange and outer face surfaces of the cover lock may have occasional blowholes up to 1 mm in diameter and up to 0.5 mm deep, in number up to three situated at a distance of at least 5 mm apart and at least 1 mm from the sharp edges.

The outer surface of the cover may have blind blowholes up to 1.5 mm in length or diameter and up to 0.5 mm deep, in number up to three, situated at a distance of at least 10 mm from one another, and up to four less than 0.5 mm in diameter and depth if they are situated at distances no less than 5 mm apart and no less than 1 mm from sharp edges.

The inner surface adjacent to the seat for the ball bearing may have occasional blind holes up to 1.5 mm in diameter or length and up to 0.5 mm deep, in number up to two, situated at a distance of at least 5 mm from one another and at least 1 mm from the sharp edge of the exit opening.

Similarly, the acceptable dimensions and positions of holes are outlined for housings as well.

§11. STABILIZING ANNEALING OF CASTING (AGING)

Hardening always takes place during the solidification process when thin-walled blanks are cast in metal molds, and to a greater degree the higher the cooling rate of the casting. The hardening gives rise to internal stresses in the casting, and these are a cause of warping of the components during machining. Stabilizing annealing or

aging is applied with the object of relieving the internal stresses. If stabilization is applied to eliminate "growth" of the parts during heating in subsequent treatment or under operational conditions, it is known as "normalization."

Apart from rapid chilling of the casting in the mold, internal stresses may be produced by differing cooling rates in various parts of the casting; also, by the temperature gradient between the surface and the internal layers in thick sections of the component, and by the resistance offered by the mold to shrinkage of the casting and other causes.

Disturbance of the internal-stress equilibrium during machining causes warping of the pieces. Moreover, the stress distribution may be such that it will act in one direction under a load, reducing the stability of the design in operation.

Internal stresses are reduced by lowering the cooling rate of the casting or reheating it to a temperature at which plastic flow of the metal, which relieves the stress, can take place. However, both methods are detrimental to the mechanical properties of the alloy. To obtain good stabilization in gyromotor-component castings made from alloy AL2, the most frequent process is aging in heated cabinets at temperatures from 200 to 250° for two hours. This temperature regime gives excellent stability in the castings together with satisfactory mechanical properties.

Thermal indicators are employed to check whether all components have passed through the proper aging regime. One such indicator is paint 754. A small amount of colorless 754 paint is brushed on anywhere on each housing and cover before stacking in the heated cabinet for aging; at a certain temperature, this material begins to darken. The extent of the darkening of the paint is a function of temperature

and heating time.

When the components are taken out of the heated cabinet, the extent to which the paint has darkened, which characterizes the correctness of the aging operation applied to the component, is noted for each housing and cover. The surfaces of the castings are inspected at the same time; the presence of blisters indicates hidden blowholes in the casting. If the casting has gas or air pores, the gas present in the pores will expand on heating to bulge out the surface of the casting.

Housing and cover blanks that have not passed through the complete aging procedure are subjected to this operation again. Components that have passed through aging and do not have swellings are sent on for machining.

Manuscript Page No.	[List of Transliterated Symbols]
24	ГОСТ = GOST = Gosudarstvennyy obshchesoyuznyy standart = = All-Union State Standard

Chapter 3

MACHINE FINISHING OF GYROMOTOR PARTS

§12. GENERAL POINTS

As was shown in §1, the gyroscope's precession rate is the lower and, consequently, the precision of the gyro instrument higher, the higher the kinetic moment of its rotor, all other conditions being equal. To increase the kinetic moment in modern gyroscopic devices, because of the limitations of their weight, it is not the inertia moment of the rotor that is increased, but its operational revolutions. An increase in the number of revolutions of the rotor demands the production of bearing parts with higher precision. Rotors revolving at high speed must be manufactured very precisely, and from homogeneous metal with high specific gravity.

Eighty-five to ninety-five per cent of the power consumed in gyroscopes is wasted in friction between the rotor and air. To reduce aerodynamic losses, the rotor and the internal surfaces of the gyrochamber must be finished with greater demands for precision and the roughness of the surface. All gyromotor parts must be made in strict accordance with the specified tolerances, and it is desirable to realize certain dimensions which ensure a first-class fit by using only part of the tolerance indicated in the blueprint. Thus one makes sure that the desired fit remains constant for the mated parts which are subjected to repeated assembling and dismantling.

So as to illustrate clearly the possibilities of ensuring the necessary conditions, we shall consider the basic causes of faults in

machining and ways of increasing its precision, as well as methods of obtaining the desired roughness of the surfaces. Without these details it is impossible correctly to work out a technical process for machining of gyromotor parts, and to ensure that they are correctly checked in the individual operations and after production.

§13. PLANNING THE TECHNICAL PROCESS

The technical process according to which the gyromotor parts and units are produced is worked out in the technical offices of the factory or workshop. The purpose of this procedure is to select the type and dimensions of the blank for the parts; the machining method and the succession of the operations; the machine-tools, fixtures , and cutters and measuring instruments most suited for machining in the given case; as well as to establish the cutting conditions and to calculate the processing time.

The basic data for planning the technical process for the gyromotor parts and units needed are: a working drawing of the part, the technical specifications, the size of the consignment and the work program, details as to equipment and factory standards. The succession of operations and transitions is determined in planning the technical processes for machining with the following principles in mind:

1. Each successive operation, transition or pass must reduce the faults and increase the surface quality resulting from the previous stage of processing. Therefore all rough operations must be carried out first, then the pre-finishing ones, and finally the finishing ones.

2. The processing of the parts must begin with those surfaces which are to serve as positioning base for the subsequent operations.

3. After processing of the positioning surface, the blank must be

based for further processing of that surface.

4. The surfaces of less precision are finished first, then the ones of greater precision.

5. Operations in which the greatest amount of spoilage is observed should be carried out as early as possible.

6. Drilling and thread-cutting should be left till the end of the technical process.

The machine for carrying out the operation must ensure the highest possible precision, within the limits of the given tolerances, for the operation in question, as well as the required cutting and feed rates.

For every operation and transition it is essential to make maximum use of the normal cutters and measuring instruments and apparatus. Special fixtures for ensuring a higher precision in the manufacture of gyromotor parts than that indicated in the instructions for the machines should be sized directly on the machines to be used for these operations. When selecting the cutting conditions, they are determined by the maximum cutting and feed depth, based on the allowance being made, the power of the machine, the hardness of the blank, how securely it is fixed, and the roughness of the surface. The cutting rate is selected in accordance with the cutting depth, the feed, the material from which the parts are made, and the type of cutter and according to tables and graphs drawn up on the basis of the standards in force at the factory. When describing the tools to be used for carrying out an operation or transition, the following data must be given: nomenclature, dimensions, size of the angles, structural peculiarities, material, and standard number. Checking and measuring instruments and equipment must also be specified for carrying out the operation.

§14. FILLING IN THE TECHNICAL CARDS

The technical process for the machining of gyromotor parts is worked out on special operational-procedure or operational-instruction cards. The already existing cards for the technical process of machining differ from each other only in details. Table 6 shows the form of one of the operational-instruction cards used for working out the manufacturing process of gyromotors.

On some cards, usually in the left-hand portion, a sketch of the part being processed is drawn, with an indication of all dimensions of the surfaces being processed and the signs for the degrees of finishing reached in the given operation. Other details given are: equipment, material, dimensions of the blank and its weight before processing. The nomenclature of the apparatus and its code are given in the "Tooling" section, in the "Fixtures" column. In the "Cutting Tools" column are entered the nomenclature of the tool, its dimensions, the size of the angles (for cutting tools, in plan; for drills — the smallest angle at the tip) and the material. The basic characteristics of the cutting tool are given in abbreviated form. In the "Measuring" column the nomenclature of the measuring instrument is noted; for a universal instrument the extent of measurement is given, for a single-measurement one — the dimensions to be measured, and for a special one — its code.

In the section "Operational conditions" the processing conditions are established, based on calculations made, which are corrected in the course of the processing, taking the latest experience into account.

In the last section are entered the priority of the operation and the norm for basic and auxiliary time. The bottom of the card shows the person who has drawn it up and the one who has ratified the process

and norm sign. Here are noted also the nomenclature of the product, the unit and the part; the number of the card, the entry sheet and the number of sheets filled in for the given operation; and the date the process was worked out.

All changes and entries on the technical cards are made in accordance with directions, and are binding for all workers of the factory. Any divergences from the established technical process are only permitted after approval by the workers of the factory which has ratified the process.

§15. PRECISION OF THE MACHINING

In contemporary instrument design, it is customary to consider the precision of the apparatus firstly from the point of view of a required precision specified by the designer, and secondly from the point of view of the precision actually achieved as a result of carrying out the process of machining the parts and assembling the apparatus.

All gyromotor parts are manufactured with a precision characterized by the tolerances prescribed by the designer for their particular dimensions. Usually the closer the actual dimensions are kept to their nominal values, the more precisely are the gyromotor parts produced.

The divergences tolerated for given dimensions of gyromotor parts and units are, as a rule, marked in the drawings. Errors in the geometrical shape of the parts must be included in the tolerances for the given dimensions if they are not specially noted in the drawings or in the operational conditions. The finishing of parts on the machines is most frequently accompanied by divergences from the correct geometrical shape. When holes are being bored and locks turned there usually occur tapering and ovalness, lack of parallelism and untrue lines. The main causes for the occurrence of these divergences are a

TABLE 6

Technical Card for Operational Instructions

1 Цех №	2 Наименование операции	3 № опер.	4 Оборудование	5 Установлены переходы		6 Инструмент			7 Режим работы					23 Разряд	8 Норма	
				13 № п.п.	14 Содержание	15 приспособление	16 режущий	17 измерительный	18 скорость резания	19 число оборотов	20 глубина резания	21 подача, мм/мин	22 число проходов		24 т. шт.	25 т. п. з.

9 Материалы	10 Размер техн. заг.	11 К-во дет. в заг.	12 Черный вес на 1 шт, кГ

26 Технологию		30 Норму		34 Изделие											38 На партию	39 Дата выпуска
27 Разработал			31 Согласовано н-к цеха	35 Прибор												Лист: 40
28 Пров. нормы			32 Проверено	36 Деталь												Листов: 41
29 Утвердил			33 Утвердил	37 Сборка												
				42 Лит. изм.	43 К-во	44 № прик.	45 Подпись	46 Дата	47 Лит. изм.	48 К-во	49 № прик.	50 Подпись	51 Дата			

1) Workshop No.; 2) type of operation; 3) Oper. No.; 4) Equipment; 5) set transitions; 6) tool; 7) operational conditions; 8) norm; 9) materials; 10) dimensions of blank; 11) number of parts per blank; 12) rough weight per item in kg; 13) No. of transitions; 14) contents; 15) apparatus; 16) cutting; 17) measuring; 18) cutting rate; 19) number of revs.; 20) cutting depth; 21) feed mm/min.; 22) number of passages; 23) priority; 24) t.sht.; 25) t.p.z.; 26) process; 27) worked out by; 28) norm check; 29) ratified by; 30) norm; 31) approved-head of workshop; 32) checked on; 33) ratified by; 34) product; 35) unit; 36) part; 37) assembly; 38) for batch; 39) date of release; 40) sheet; 41) number of sheets; 42) measurements on casting; 43) quantity; 44) order No.; 45) signature; 46) date; 47) measurements of casting; 48) quantity; 49) order No.; 50) signature; 51) date.

lack of precision in the machines, mandrels and the tools; the presence of a constantly active factor — the cutting force, which causes a deformation of the part being processed, etc.

On establishing the conditions for the machining of gyromotor parts it is essential to bear in mind that the precision of the processing is closely connected with its work capacity and cost. Precision in the manufacture of parts depends to a great extent on the precision of the blanks, on the methods used for the preliminary and final processing of the parts or units.

To ensure precision in the machining of gyromotor parts within the limits of first- and second-class tolerances it is essential to establish the causes of initial faults. Once these causes are known, a technical process for machining gyromotor parts and units can be drawn up which will ensure their production with the essential precision and surface roughness in accordance with the drawing and operational conditions.

§16. CAUSES OF ERRORS AND WAYS OF DISCOVERING THEM

Although precision machines, perfected machining methods, and precision measuring instruments are used for the final operations in the manufacture of gyromotor parts and units, and although other conditions are observed which affect the precision of the machining, it is impossible to achieve absolutely precise dimensions and a correct geometrical shape.

The main causes of faults in the processing of gyromotor parts consist in the following errors:

1) lack of precision in the machine and tool;

2) those due to deformations in the elastic system formed by the machine, the part and the tool;

3) those caused by temperature deformations;

4) from deformations occurring under the influence of internal stresses in the parts;

5) in measurement;

6) because of wear to the tool blade, lack of precision in its shape, dimensions and base (resultant errors).

Faults Arising from Lack of Precision in the Machine and Tool

For testing the precision of machines, the appropriate GOST "Precision Standards" are normally used, in which methods are laid down for testing individual units and the machine as a whole.

In the case of turning lathes, the following elements of geometrical precision are tested:

– radial and face pulsation in the spindle;

– straightness and parallelism of the guides;

– parallelism of the spindle shaft to the direction of motion of the carriage table;

– perpendicularity of the planes, geometrical axes and various parts of the machine.

The set norms for spindle pulsation in turning lathes do not satisfy the demands of precision for machining bodies and covers of certain high-precision gyromotors. For the processing, the spindle pulsation is reduced, by adjustment and tightening of the sliding spindle bearing, to a value not exceeding 2 μ, which ensures the essential precision for machining bodies and covers.

If the spindle pulsation is higher the ball-bearing holes bored turn out eccentric and do not ensure the tight fit of the ball-bearing.

Processing faults in the form of tapering during the boring of apertures and the turning of external surfaces of the parts occur as a result of lack of parallelism in the guides in relation to the center shafts. For preventing spoilage in gyromotor parts through lack of

precision in the machines, the latter must be subjected, apart from periodical repairs, to compulsory testing in accordance with a special precision graph.

The lathe accessories used have a great influence on the precision of the machining. Normally the precision in the manufacture of accessories must be higher than the precision in the part or unit being machined. The tapered spindle mandrels and fixtures must be adjusted to fit the spindle hole, then mounted on the spindle, which has previously been rubbed down, lightly greased and heated. Before installing the mandrel, the machine is allowed to run for a certain time with no load.

Precision in processing a part or its individual sections depends on the method of mounting and fixing, as well as on precision and shape of the tool used. Wear on the tool, which is unavoidable in the course of the work, causes errors in the dimensions of the parts, particularly in the final operations.

Wear occurs irregularly. At the beginning of the cutting the sharp tip of the cutting tool becomes blunter; for some time the cutting instrument runs without noticeable wear; as the cutting proceeds a normal amount of wear occurs, proportional to the extent of cutting. Then a forced wear of the tool sets in, which causes not only a loss of precision, but also a sharp increase in the roughness of the surface being processed.

Errors Due to Deformation in the Flexible System Formed by the Machine, the Part and the Tool

When being processed on the machine the part is subject to deformation as a result of the stresses in its fastening, cutting stresses, its own weight, unbalanced parts of the machine and of the part itself which cause forces of inertia during revolution.

When considering the extent of a deformation from these causes

one notes that the cutting forces during the processing of a part change with a change in the allowance, in the hardness of the surface being finished and in the condition of the cutting edge of the tool.

Deformation resulting from the fastening of the part in the chuck or other clamping device fluctuates greatly, particularly when a hand clamp is used. When parts are clamped in collet devices with a large cylindrical finished surface the deformation is but slight, and with parts of rigid construction it is practically absent. Therefore only collet arbors are used for fixing gyromotor parts in the final operations of their processing.

Deformations in parts being processed resulting from the flexibility of the machine-part-tool system may be calculated according to the appropriate formulas, using experimental data on the rigidity of machines of various types.

The turning of gyromotor parts to increase the precision is divided, as a rule, into preliminary and final processes.

In the preliminary process it is essential to aim at achieving a correct geometrical shape for the semi-finished part, since an ovalness will in the end cause, although to a lesser degree, an ovalness in the finally processed part. In its turn, a tapering in the blank will lead to a tapering in the finished part. Any fault in the blank and the semi-product will be repeated to some degree in the finally processed part as well.

The final processing must be carried out with a small cutting depth and feed, which will reduce the cutting stress and, consequently, the stress which causes a deformation in the system as a whole affecting the precision in the finish of the part.

Errors Caused By Temperature Deformations

Temperature deformations in the part occur as a result of heat

arising during the cutting process, of friction in the moving units of the machine, of heating and cooling of the machine-workpiece-tool system or fluctuation in the room temperature. The influence of heat deformations on the precision of the finish of gyromotor parts is particularly marked during the final processing of the ball-bearing holes and collars and of the locks, which is normally carried out to the first and second degree of precision.

As a result of heating of the headstock on a turning lathe, owing to heat production in the work of the bearings, the spindle shifts horizontally and vertically. With an increase in the cutting rate and feed the temperature of the part drops, while with an increase in the cutting depth it rises. Temperature deformation in the instrument depends on cutting rate and depth, feed, the overhang of the cutter, its transverse cross section, the thickness of the hard-alloy plate and the hardness of the material being processed.

Faults due to heat deformations in the whole machine-workpiece-tool system decrease to a considerable extent when the part and tool are cooled with cutting fluids.

One of the basic conditions for ensuring high precision (to the first degree and above) in the manufacture of gyromotor parts is the constant normal temperature of the whole machine-workpiece-tool system during the final processing. For this purpose a special apparatus (see Chapter 6) which maintains a constant temperature and humidity in the surrounding air is used at some works in the room where gyromotor parts are finished and tested. In accordance with OST 85002-39 the normal temperature is taken to be +20°C. For the same purpose special heat-regulating devices which ensure a regular temperature in the part being processed and in the relevant units of the machine-tool by means of a variation of the feed quantity of the coolant are included in the

designs of certain precision grinding and lapping machines.

Errors From Deformations Arising From Internal Stresses in the Parts

Internal stresses in gyromotor parts arise as a result of production of the blanks for these parts by casting, forging and stamping and of their subsequent thermal and mechanical treatment. When casings and covers are cast under pressure internal stresses manifest themselves on cooling of the molten metal; in the case of forging and stamping, stresses occur because of irregular plastic deformation; during thermal and mechanical processing – because of irregular heating of the blanks.

Internal stresses in blanks produced by casting, forging, hot and cold stamping, may be eliminated or considerably diminished by heating and holding at a definite temperature and under definite conditions. The operational conditions for eliminating internal stresses in casings and covers are given in Chapter 1, those for other parts are mentioned in the description of the manufacturing process.

During the machine finishing, stresses which considerably affect the precision arise in the surface layer of the parts which are undergoing plastic deformations. The metal in this layer proves to be strengthened and has a greater hardness. This strengthened layer may be removed by mechanical processing under optimum conditions or by thermal processing. To reduce internal stresses, particularly in parts of less rigidity, and to strengthen the surface layer, it is essential carefully to select the operational conditions for the final processing so that inadmissible deformations in the part are not caused.

Errors in Measurement

Gyromotor parts are subjected to repeated measurements in the course of their production. Faults due to measurements are liable to

vary greatly. They depend on the method of measurement and on the precision of the measuring instrument.

Errors in measurement make it necessary to narrow the tolerance allowed for all other processing faults. To reduce faults in measuring, all measurements of the part must be made with a measuring instrument which ensures a calculating precision appropriate for the part being produced.

The parts must be measured at a specified temperature, both during production and when being tested. The measuring instrument must be an approved model and must be certified.

Resultant Errors

In the process of mass production of gyromotor parts errors arise in the machine-finishing operations which are caused by various factors and which occur with varying frequency. Some errors are systematically repeated, while others are random. The resultant error of any dimension has arisen as a result of constant and variable, systematical and random errors. An estimation of resultant errors is made according to their constituent elements by a computed-analytical or by a statistical method.

The method more commonly used in industrial conditions is the statistical one, which is based on the principles of the theory of probability and mathematical statistics. For an estimation of resultant errors a batch of parts is finished according to a specific technical process, their dimensions are measured, and the regularity of occurrence of these dimensions is noted. On the basis of the results of the measurement of the dimensions in question, distribution curves are plotted, from which we may determine the maximum value of the resultant error.

§17. BASIC METHODS FOR RAISING MACHINING PRECISION

Basic methods of increasing the precision in the machining of gyromotor parts are:

1. Increasing the rigidity of the system formed by the machine, the workpiece and the tool.

2. Carrying out the final processing on precision machines with minimal spindle pulsation.

3. Processing with only one setting, or with the smallest number of readjustments.

4. Use of cutting tools in the final processing which have hard-alloy plates, are ground fine and have lapped cutting edges.

5. Carrying out the final processing operations at high speeds and with optimum feeds.

6. Use of the most efficient coolants.

7. Use of mandrels and fixtures which are sufficiently rigid, balanced and adapted to the lathe spindle.

8. Use of a rigid measuring instrument which ensures the necessary precision and output.

9. Maintenance of a constant, and, even better, normal temperature in the room during the finishing and testing of parts.

10. Measurement of the critical parts after they have cooled down to room temperature (for rapid cooling they may be placed in a cooling medium).

§18. ROUGHNESS OF THE SURFACE BEING FINISHED

In the course of the machining of parts, marks left by the cutting tool remain on the surfaces being processed. These take the form of ridges and hollows which create a definite roughness of the surface. The degree of roughness, or of micro-irregularities, which is defined by the height of the ridges and by the depth of the hollows, has a

considerable effect on the operating characteristics of the gyromotor parts — friction in the settings, wear resistance, strength, corrosion resistance, etc.

The structure of the surface layer of the metal being processed undergoes a change down to a certain depth under the influence of the tool. When the upper layer of metal is removed from parts, the remaining layer is strengthened, as was described above, on account of the cutting stress. The depth of the strengthened metal depends on the method and conditions of cutting and varies from hundredths to tenths of a millimeter. This strengthening of the surface layer of the metal changes its characteristics in comparison with the basic metal from which the part is made.

Ridges and hollows situated in the direction of feed cause transverse roughness, while those in the direction of cutting cause lengthwise roughness. Normally transverse roughness is greater than lengthwise and thus determines the roughness of the surface. When defining the degree of finishing, the transverse roughness is measured.

The character of microgeometrical irregularities (roughnesses) on machined surfaces of parts depends on cutting rate, feed, cutting depth, wear on and geometry of the tool, the mechanical qualities of the material being processed, the material of which the instrument is made, the coolant, the quality of grinding and lapping of the tool. On grinding, the roughness of the surface being processed also depends on the granularity of the grinding wheel.

The greatest influence on the microgeometry of the surface being finished, whatever the processing method, is exerted by the feed. When one examines the finished surface it is easy to detect traces of the movement of the cutter. The height of the ridges is

$$H_p = \frac{S^2}{8r}, \qquad (4)$$

where H_p is the height of the ridges, S is the feed per revolution, r is the radius of curvature of the cutter.

From Formula (4) it can be seen that the height of the ridges is directly proportional to the square of the feed, and inversely proportional to the radius at the point of the cutter. However, because of the complexity of the process of chip formation, Formula (4) only reflects qualitative dependences and one cannot use it to calculate the height of the ridges.

It has been established experimentally that with comparatively low feeds a further reduction does not lead to a decrease in the roughness of the surface being processed. Therefore in the course of a precision finishing turning operation there is no point in decreasing the feed below a certain value (usually S_{min} = 0.02-0.03 mm/rev).

The second of the basic factors affecting the roughness of the surface being finished is the cutting rate. It has been established by investigations that with an increase in the cutting rate the surface roughness at first increases, reaching a certain critical value, at which point the surface is at its worst. This is also connected with the sharp increase in the cutting stress and the appearance of vibrations. With a further increase in the cutting rate the surface roughness decreases. This phenomenon is particularly to be observed when steel is being processed.

If the machine-workpiece-tool system is sufficiently rigid, the cutting depth hardly affects the roughness of the surface being machined. The cooling liquid has a considerable effect on the surface roughness, allowing the chips to slide easily down the front face and reducing friction between the clearance surface of the cutting tool and the product. The carefully lapped faces of the cutting tool ensure that during the finishing process surfaces are obtained with a

low degree of roughness.

The influence of other factors on the roughness of the surface being processed is not considerable.

§19. CRITERIA FOR ESTIMATING SURFACE ROUGHNESS

When defining the roughness of a finished surface its microgeometry is estimated according to a classification laid down in GOST 2789-59, due to be introduced in 1962 in place of GOST 2789-51. For estimating surface roughness the following parameters are accepted in GOST 2789-59; R_a is the mean arithmetical deviation of the profile (instead of H_{sk} – the mean square deviation as per GOST 2789-51), and R_z is the height of the irregularities (instead of H_{sr} as per GOST 2789-51). These parameters correspond to recommendation ISO No. 221 and are accepted in the standards of Great Britain, Italy, the USA, etc.

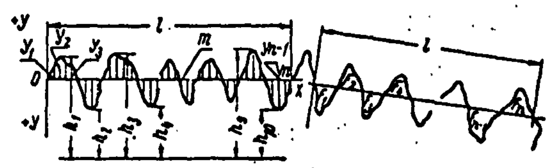


Fig. 17. Profilograph of surface irregularities.

An estimation of surface roughness according to the new criteria will make it possible to simplify designs and to increase the precision of the readings on the instruments for estimating surface roughness, as well as to reduce considerably the time needed for obtaining the mean arithmetical deviation according to the profilograph.

A new parameter has been introduced – the base length l (see Fig. 17). To keep the new standard in line with the old one the 14 degrees of surface finish have been preserved, and the values of R_a and R_z $\left[R_a = \frac{\sum_1^n |Y_i|}{n};\ R_z = \frac{(h_1 + h_3 + \ldots + h_9) - (h_2 + h_4 + \ldots + h_{10})}{5}\right]$, taking the base length into account, have been fixed near the values of H_{sk} and H_{sr}

as per GOST 2789-51. The maximum numerical values of roughness according to the criteria R_a and R_z with set base lengths are given in Table 7.

When the measurement of surface roughness must be made on a base line differing from the values shown in Table 7, its value is chosen according to the sequence 0.08; 0.25; 0.8; 2.5; 8 and 25 mm. In this case, the basing line is indicated in the technical specifications for fabrication of the components, subassembly and product.

All degrees of surface finish are denoted by one sign* — an equilateral triangle, alongside which is indicated the number of the class or the number of the class and the category, e.g., ∇7, ∇7b. Since in the new standard the numerical value of surface roughness limits only the highest roughness value according to the criteria R_a or R_z, if it is essential simultaneously to limit the maximum and mini-

TABLE 7

Classification and Denotations of the Degrees of Surface Finish

1 Класс чистоты поверхности	2 Среднее арифметическое отклонение профиля R_a, мк	3 Высота неровностей R_z, мк	4 Базовая длина l, мм
	5 не более		
1 2 3	80 40 20	320 160 80	8
4 5	10 5	40 20	2,5
6 7 8	2,5 1,25 0,63	10 6,3 3,2	0,8
9 10 11 12	0,32 0,16 0,08 0,04	1,6 0,8 0,4 0,2	0,25
13 14	0,02 0,01	0,1 0,05	0,08

1) Class of surface finish; 2) mean arithmetical deviation of profile R_a, in μ; 3) height of irregularities R_z, in μ; 4) base length l, in mm; 5) not exceeding.

mum roughness values in the denotation, two degree or category numbers must be given. For example, ∇9-10 denotes that the roughness according to R_a should be not less than 0.16 and not more than 0.32 μ.

A surface roughness exceeding the first class laid down in GOST 2789-59 is denoted by the sign V, above which is marked the height of the irregularities, R_z, in microns, e.g., $\overset{500}{V}$. The numerical values of R_z, taken from the 10th sequence according to GOST 8032-56, are 400, 500, 630, 800, ...

The classification and denotations of surface roughness are laid down for industrial products made of any materials, including wood.

Special instruments are used for estimating the microgeometry of finished surfaces; a description of some of them is given below.

§20. INFLUENCE OF SURFACE ROUGHNESS ON THE QUALITY OF GYROMOTORS

The quality of movable and immovable fits, the strength under dynamic load, and corrosion and wear resistance depend on the quality of the machined surfaces of the parts of gyromotors and especially on their microgeometry. A good surface quality reduces the energy losses during work and gives the pieces a beautiful external appearance. Thus, the quality of finished surfaces of gyromotor parts affects precision, working life and the operational reliability of gyromotors.

The Influence of Surface Roughness on the Fit of Parts to be Mated

The quality of fit of ball-bearing races on the neck of the rotor shaft and in cover and housing seats depends essentially on the roughness of the finished surfaces of the necks and seats. No other immovable joints of the parts of gyromotors can achieve the desired fit when mated, even if the dimensions of the surfaces to be mated are correctly observed, if the roughness of their surfaces is one class lower.

When the diametral dimensions of the parts are measured, the meas-

urement actually refers to the crests of the hills which are broken down in the various stressed fits. After this the bore diameter increases, and the outer diameter of the part to be mated decreases.

When the surface roughness is high it often happens that ball-bearing races can originally be put onto the neck of the rotor shaft or into the seats in the cover or housing only by force, but when they are taken out and then again put onto the same shaft neck or into the same seat they do not give a sufficiently strong fit, because the hills by which originally the necessary fit was effected have been broken down, and the dimensions of the parts have changed. Such phenomena may also happen when gyromotors are repeatedly taken apart and assembled, when the ball-bearing races are taken from the neck of the rotor shafts and out of the bearing seats in the covers and housings, and the housing seating lock is removed from the cover. For this reason the fitting surfaces in gyromotors of high precision are finished to roughnesses of the 9th to 10th classes.

Influence on Strength

The various surface indentations and scratches on a rough-machined part act in a sense as cracks that are gradually enlarged under alternating load leading to breakage of the part. Most dangerous are surface roughnesses near transitions from one diameter to another, because the stresses are usually concentrated at such points. For the same reason a noticeable reduction of fatigue strength of a metal is observed near transitions from a fine machined surface to a more roughly machined one.

For example, the strength of a fine polished specimen was found experimentally to exceed that of a ground one by 10 to 15%.

Influence on Corrosion Resistance

Investigations have shown that the corrosion resistance of ma-

chined surfaces shows an inverse dependence on surface roughness. The explanation is that moisture and other corroding agents are usually accumulated in the valleys of the surface roughnesses whose size and number are larger on surfaces machined to lower finishes. Figure 18 shows a surface with valleys in whose bottoms corroding agents are accumulated; their action spreads in the directions denoted by arrows in the figure. As a result of the corrosion, the ridges are separated from the metal surface, after which new roughnesses are formed, and the corrosion begins to spread from the new valleys.

Fig. 18. Nature of propagation of corrosion.

Experience shows that uncoated surfaces with minor roughness obtained by surface machining resist corrosion for a longer time than rough-machined surfaces. For this reason, parts of gyromotors that have no anticorrosion coating should be machined to a high finish.

Influence on Wear

The wear of parts is always characterized by a considerable change of dimensions in the first period, because rapid leveling of the hills takes place. When the mated surfaces are rough-machined and their hills attain large dimensions, fast leveling of the hills takes place in the very first period, the gap between the surfaces increases rapidly and, consequently, the operating precision of the instrument is spoiled. The operational reliability and the working life of a gyroscope depend essentially on maintenance of the fit clearances specified by the design during the whole operational period. For this reason it is necessary to machine the corresponding surfaces of the parts to high finish classes. Thus, the shafts, seats and ball races of ball bearings are machined to a roughness of class 11 to 12, and the balls to class 12 to 14.

Proper roughness of the machined surfaces of gyromotor components also has the purpose of giving them good external appearance, and low roughness of the inner surfaces of the housing, cover, and rotor is necessary to reduce air friction during work and, consequently, to reduce the power drawn by the gyromotor.

§21. METHODS FOR ACHIEVING REQUIRED SURFACE ROUGHNESS

The roughness of a machined surface and its quality after a given machining process depend on the material of the workpiece (chemical composition, structure and mechanical properties), on the construction of the machine (its rigidity), on the construction and quality of the cutting tool, and on the machining formula.

Thus, when steel parts are machined, their surface roughness depends on carbon content and on hardness. Structural steels with high carbon content usually have a lower surface roughness after machining than steel with low carbon content. In order to attain low surface roughness, steel parts are subjected to special heat treatment, as will be seen when we describe the manufacture of a gyromotor rotor.

When the parts are machined with metal-cutting tools, the size of micro-unevennesses on their surface is mainly affected by the combined action of the following factors: a) by the geometry of the cutting tool which influences the transverse roughness; b) by ductility phenomena when the chip is separated, by which metal particles are torn out and the worked surface region behind the cutting edge recovers elastically. This, in turn, causes friction of the back surface of the tool during the cutting process; c) by vibration of the workpiece and the tool which mainly causes longitudinal roughness.

A strong influence on the roughness of the worked surface is exerted by the geometry of the cutting tool, and by the working conditions, cutting speed, and especially, as mentioned above, by the feed.

If the feed is reduced, the roughness of the worked surface is reduced, but in fine turning it is not advisable to reduce the feed below a certain value (usually 0.02-0.03 mm/rev), because a further reduction does not reduce surface roughness, while the time required for working is increased.

As stated before, the cutting depth has but little influence on surface roughness if the machine-workpiece-tool system is sufficiently rigid, and therefore it can be determined mainly according to the allowance to be removed in the given process.

The cutting speed also affects the roughness of the surface to be machined. Investigations have shown that with increased cutting speed the surface roughness first increases, but then decreases. If silumin or other nonferrous alloys are to be machined, this phenomenon is less characteristic than in the case of steel. With increasing cutting speed the surface roughness is reduced insignificantly because a metal buildup is formed. The metal buildup formed on the surface on the front plane of the cutting tool affects the microgeometry and structure of the machined surface, which is explained by its strong friction with the machined surface. In order to reduce the influence of the buildup the surfaces of the cutting tool must be polished to reduce friction. Since the buildup formation is connected with a rise of temperature in the cutting zone owing to friction with the contacting surfaces, cooling and lubricant liquids may be used to reduce the temperature in the zone of chip formation and to prevent buildup formation.

In the machining of metals, lubricant and cooling liquids have mainly three physicochemical functions: lubrication, cooling, and flushing.

The lubricating action of the liquid consists in the formation of

a lubricating layer on the surfaces of the workpiece and the tool which take part in the machining process. It considerably reduces the frictional forces, which cause wear of the cutting edges and form a buildup on the tool.

The cooling action of lubricating and cooling liquids consists in the absorption of the heat produced in the cutting process; the liquid removes heat by evaporation and heat transfer.

The flushing action of the lubricating and cooling liquid consists in the mechanical removal of fine chips and particles from the machined metal, which contaminate tool and workpiece, and it prevents particles from sticking to the surface of the workpiece and the tool.

Such a multiple action of the lubricating and cooling liquid during machining allows the roughness of the worked surface to be reduced by its application.

If the surface is worked with a carefully dressed tool, a considerably lower surface roughness is attained, because experience has proved that unevenness of the cutting edge of the tool is transferred to the machined surface in enlarged dimensions. The more the cutting edge grows blunt, the more the roughness of the machined surface is increased. In practical work, considerable deterioration of the surface means that the tool must be exchanged.

Longitudinal surface roughness is caused by the vibration of the machine-workpiece-tool system, which may be transferred from other vibrating machines and assemblies through the floors, ceilings, etc. For this reason, the foundations of precision machines should be reinforced and should have insulating pads, and machines should only be installed on the ground floor. Vibration of the system may be caused by the action of unbalanced masses of rotating parts, of the tool or parts of the machine, and also by defects of the transmission of the

machine, which may consist of poorly assembled gears, bad belt seams, etc. For this reason, all rotating parts of machines and fixtures serving to hold the work pieces are carefully balanced. Belts should be bonded together, and the cutting tools should be held with short projections.

§22. MEASUREMENT OF THE ROUGHNESS OF MACHINED SURFACES

The instruments for measuring the roughness of machined surfaces may be divided into two groups according to their mode of operation:

1) contactless instruments, which evaluate the microgeometry without touching it (most optical instruments belong to this group);

2) contact instruments, which evaluate the microgeometry by contacting the surface to be tested with a sensitive element of the instrument (stylus instruments, electrocondenser and certain types of pneumatic instruments belong to this group).

The instruments of each group have their advantages and drawbacks, and they are used depending on the specific conditions and the test requirements.

In the manufacture of gyromotor parts, optical as well as stylus instruments are used for determining the finish classes of the machined parts.

Under workshop conditions, the most productive method for determining the roughness is a visual control method based on comparison between the surface to be inspected and a specimen surface, for which roughness standards are used. Sometimes special parts are made — specimens characteristic for the surface of the parts to be machined in the workshop. The roughness standard specimens must be made of the same metal and by the same machining procedure as the parts to be tested. The geometrical shape of the standard specimen and that of the part should be the same. When a batch of parts with given surface

roughness is manufactured, it is advisable to compare the first part with the standard specimen of the given class when it is finished; the other parts may only be manufactured if this comparison has satisfactory results. Comparison microscopes are used for comparison of the surface roughness of the part with the standard.

Comparison microscopes, in contradistinction to ordinary microscopes, eliminate the necessity of keeping in mind the image of the standard surface during comparison.

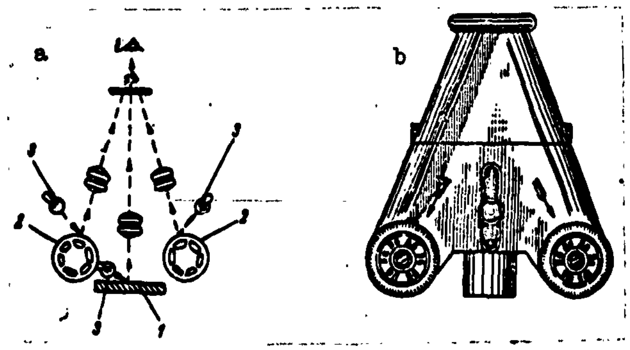


Fig. 19. Comparison microscope. a) Optical scheme; b) external appearance. 1) Part to be tested; 2) drum with roughness standards; 3) illumination lamps.

Figure 19 shows a comparison microscope. In this instrument, one lamp illuminates the surface of the part, and two others the surfaces of standards which are arranged on special drums. The optical scheme is arranged so that one can see in the field of view the roughness of the part and of the standards at the same time. Each of the drums contains six standards. By turning the drums, the standard specimens are located so that on one side there is the standard with the next rougher surface to the surface of the part, and on the other side the standard with the next finer surface. In such an arrangement one can safely say that the roughness of the surface to be measured lies in the roughness range of the standards. The finish classes of the standards are indicated on the outside of the drums and the roughness of

the surface to be measured is determined from these indications. Surface roughness between 8th and 11th class are evaluated in the microscope.

If it is not possible to arrange a comparison microscope on the surface to be tested, and if it is not possible to measure the surface roughness with other instruments without destroying the part, e.g., with holes in the cover under the ball bearing, surface roughness is measured by the replica method.

The replica method consists of the following: a replica of the surface to be tested is taken on a suitable material to which it transfers its roughness. The finish class of the surface on the replica is determined visually or in the MIS-11 binocular microscope.

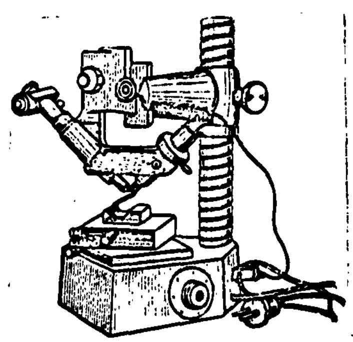


Fig. 20. Linnik MIS-11 binocular microscope.

The construction of the MIS-11 binocular microscope (Fig. 20) with variable magnification, which is manufactured in series by the domestic industry, is useful for the determination of roughnesses between the 3rd and 8th classes, inclusive. The instrument is used in laboratories for research work, and also for certifying roughness and replica specimens.

The construction is based on the principle of measuring the microprofile height obtained by the so-called light-section method. When the degree of roughness of plane surfaces is measured, the part is located on the microscope stage. When cylindrical surfaces are measured, the part is placed on a special prism. The surface to be measured is illuminated by some external light source, and the observation barrel is adjusted first. The microscope frame is displaced by means of the rack gear and a micrometer mechanism, and the component's surface is

focused sharp in the microscope objective. The part of the surface to be measured must be visible sharply focused in the center of the field of view. Then the external light source is switched off, and the inclination of the illumination tube is changed by means of an adjusting screw with the illumination lamp switched on, until the green band, which gives the image of the slit, appears in the field of view. When a sharp image of the slit has been attained by corresponding adjustment, and when a sharp image of the surface has been obtained, the microscope is prepared for the roughness measurement.

In order to measure the roughness height the filament of the ocular micrometer, which was initially set parallel to the slit image, is brought to coincidence with the curvature peaks of the slit image, which correspond to the roughness peaks of the surface, and the height can be read from the scale of the screw micrometer in scale divisions. Then the filament of the ocular micrometer is brought to coincidence with the valleys of the slit-image curvature, and again the scale divisions of the ocular micrometer are read. In order to determine the height of the roughness in microns, the difference between the two scale-division readings is multiplied by the value of the ocular micrometer scale division.

Microinterferometers are used for evaluation of surface roughness after fine-finishing operations such as are applied to the finishing of the balls and races of ball-bearings, in the limits between the 10th and 14th classes. For the introduction of GOST 2789-59 it is necessary to elaborate designs and initiate production of instruments for the determination of surface roughness according to the R_a criteria (mean arithmetic profile deviation) and R_z (average roughness height).

§23. ROTOR BLANKS

Blanks for rotors are cut from bars of round cross section with

diameters up to 50 mm on turret lathes, for larger diameters on circular saws or power hacksaws. Because of the short length of the workpieces the bars are not straightened.

There are two types of machines for cutting the blanks for rotors from the bars with circular saws (Fig. 21): with constant saw feed and with constant saw load. On machines with constant feed the load is usually small at the beginning and at the end of the cutting process but large in the middle (see the cut areas per saw revolution on Fig. 21a). On machines with variable feed it is possible to cut with constant power from the beginning to the end of the cut by varying the feed (Fig. 21b). Usually the feed is automatically controlled by a weight or by the hydraulic drive. Workpieces of small diameters are cut in bundles, which effects a great saving in setup, cleanup and machining time. When bundles are cut, the bars are held by special clamping devices (Fig. 22). The workpiece cutting speed on a machine of either type is chosen according to the material and its diameter.

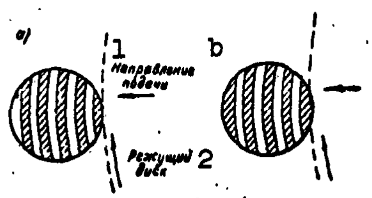


Fig. 21. Schemes of metal cutting: a) constant feed; b) constant power. 1) Direction of feed; 2) cutting disk.

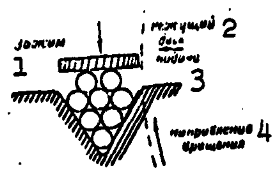


Fig. 22. Cutting of workpieces in bundles. 1) Clamping; 2) cutting disk; 3) feed; 4) direction of rotation.

Blanks for rotors are cut with an allowance for spotfacing of the end faces, the size of which depends on the quality of the cut and the bar diameter. Usually, an allowance of 1 mm is made for spotfacing each end of blanks 40 to 50 mm in diameter; from 50-70 mm, it is 1.5 mm, and 2 mm from 75-100 mm.

Blanks with a diameter of more than 100 mm are produced by forging to give them a shape approximating a simplified contour of the

rotor shape (see broken line in Fig. 5). The machining of the rotors from the forgings is characterized by the removal of considerable allowances, and great expenditure of labor and material. Forged blanks are used for rotors of comparatively large dimensions, and if small orders are to be manufactured. More frequently, workpieces are used which are stamped hot under presses in special dies from blanks which were cut by one of the methods described above; the dimensions and shape attained here are near to the dimensions and the shape of the finished rotor, and the expenditure of labor and material is greatly reduced. Hot stamping of blanks for rotors is widely used when they are manufactured from nonferrous alloys.

§24. THE WORKING OF ROTORS ON THE LATHE

The lathing of rotors of gyromotors is subdivided into preliminary lathing before and after normalization, final lathing before pressing the shunt-wound iron pack of the rotor, and final lathing after pressing. As the machining of rotors of almost all types of gyromotors consists of analogous machining operations, we shall consider the technology of manufacture for only one rotor type.

Preliminary Lathing before Normalization

When rotor blanks are premachined on a lathe, large chips result; therefore, the blanks must be firmly fixed in the chuck. The sequence of rotor blank machining is shown in Fig. 23. The machining of a blank begins with finish spotfacing of one end (Fig. 23a), turning of diameter D over length l as far as the jaws of the chuck, and turning the journal to a diameter d on a length A with an allowance for the diameters which is approximately twice d. After this the blank is turned round and the second end is spotfaced (Fig. 23b), holding length A_1; then the blank is turned to a diameter D with an allowance of 1-1.5 mm for further machining, and then the second journal is also turned to

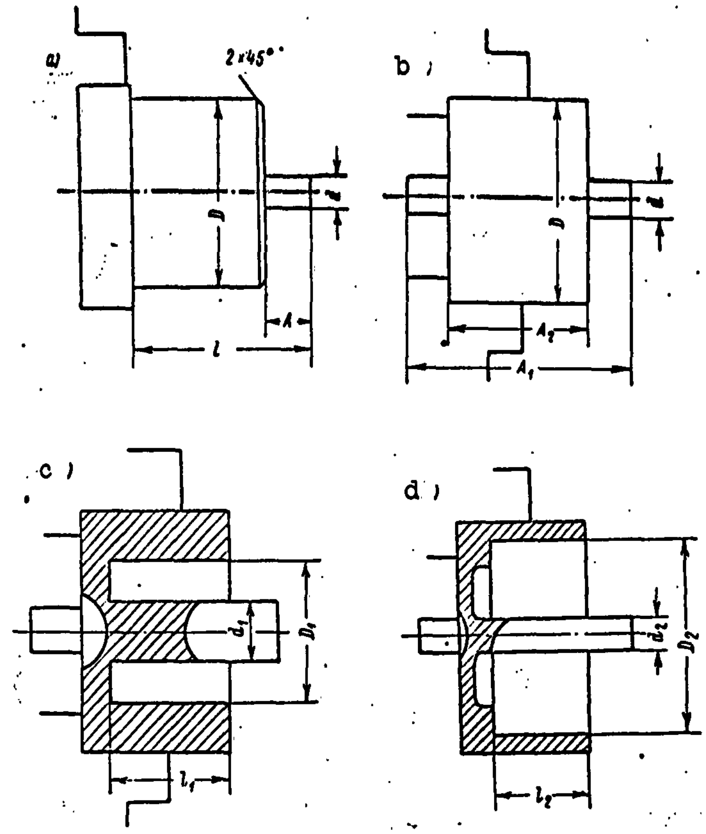


Fig. 23. Sequence of rotor machining before normalization.

diameter d. Spotfacing and turning is carried out with undercut tools of high-speed steel or with T15K6 hard-alloy tips.

After this the bore is rough-bored to a depth of l_1 and a diameter of D_1 (Fig. 23c) and then shouldered (Fig. 23d) to a depth l_2 and diameter D_2 for the iron pack and the bottom is turned with a radius, leaving an allowance of 1.5 to 2 mm for subsequent machining. Simultaneously with the boring, the outer surface of the shaft is turned to a diameter d_2 over its entire length.

Normalization

The rotor, having first been turned on its outer diameter and bored, is normalized in heat treatment which consists of preliminary

hardening and a subsequent high-temperature tempering. During the hardening the carbides are recrystallized, and the high-temperature tempering improves machinability of the rotor material owing to the formation of a very favorable fine-grained structure; hardness is increased and internal stresses which had arisen during preliminary machining are eliminated.

Hot-stamped rotor blanks made of nonferrous alloys are annealed before rough machining to eliminate internal stresses; after this they are etched and rinsed, and then they are first rough and then finish-machined.

Rough-machined rotors of 35KhMYuA steel are placed for normalization in a furnace at a temperature between 500 and 600° in separate batches, which are stacked directly on the furnace hearth and kept there for 30 minutes. Then the furnace temperature is raised to 930-970°, a close watch being kept on the blanks as they are heated up. When the color of the blanks is the same color as the color of the furnace hearth, this means that the blanks are heated to furnace temperature. The blanks are kept at this temperature for 12 minutes. After this they are taken out of the furnace with tongs and quenched in oil. The oil temperature must not exceed 60°. The cooled blanks are taken out of the oil and tempered. For this purpose the rotor blanks are put in separate batches directly onto the hearth of a furnace heated to 650-670°. As during hardening, the blank temperature is determined by comparing the color of the blanks and that of the hearth. The blanks are held for 35 minutes at this temperature; then the temperature of the furnace with the blanks is lowered to 600° and the blanks are unloaded. They are cooled to the temperature of the surrounding medium, in air or in an oil bath.

Correct tempering is determined by testing the "B" hardness with

a Rockwell instrument; the hardness should be between 91 and 98 units. If hardness is too high or too low the heat treatment must be repeated. This can be done only once.

The twofold heat treatment described above increases hardness slightly, and assists in producing the required roughness of the rotor surface.

Rotor blanks made of carbon steels or nonferrous alloys are normalized with a heat treatment commonly used for these alloys; the aim is to obtain a fine-grained structure and to equalize structural nonuniformities, to improve machinability, to increase hardness and mechanical properties, and to eliminate internal stresses after preliminary machining.

Preliminary Turning after Normalization

The machining of rotor blanks with lathes after normalization is divided into preliminary and final machining. The sequence of machining is shown in Fig. 24. For preliminary machining the rotor blanks are mounted on a lower-precision lathe with three-jaw chucks by the inner preliminary bore (expansion mount) with thrust support (Fig. 24a). The journal of the shaft is spotfaced to a length A' and turned to diameter d'; after this the end of the rotor flywheel is spotfaced to a length A'_2 and turned to the diameter D', removing a chamfer of 2.2 [mm] by 60°. The rotor is set up with its outer surface up to the rest in pot chuck bored on the lathe (Fig. 24b). The second journal is clamped and spotfaced, holding to a total length A'_2; without removing the handwheel, the rotor face is spotfaced to length A''_2. Once the ends are spotfaced, the rotor is bored to the diameter D_2 of the iron pack with an allowance of up to 0.3 mm for final machining and the bottom is also spotfaced (Fig. 24c). Then the diameter d'_2 of the journal inside the bore is turned and both surfaces with diameter d_3 are turned for the thread of the journals.

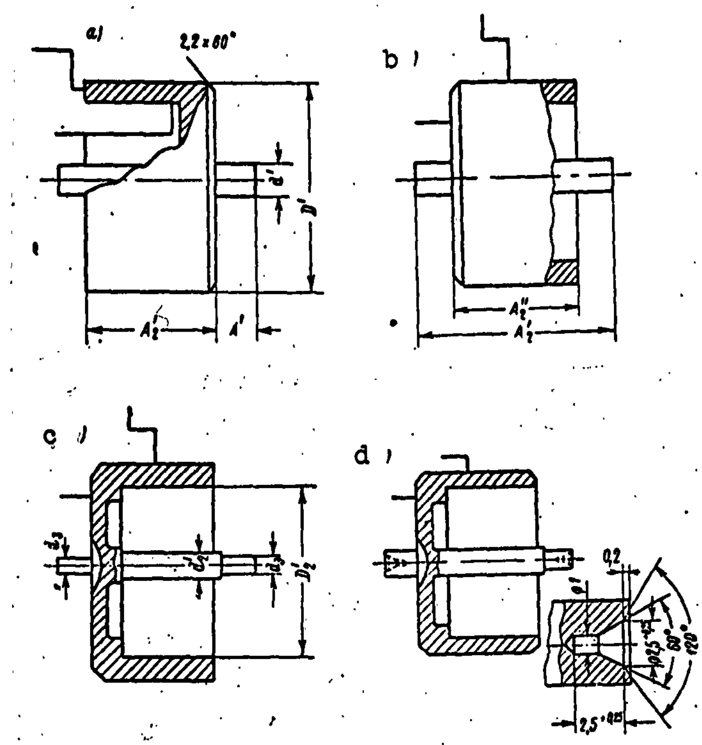


Fig. 24. Sequence of rotor machining after normalization.

Since during the heat treatment the surface layer is carburized to a considerable depth, the blanks have large allowances before heat treatment. Therefore, the blanks are sometimes rough-machined with two setups, repeating the operations shown in Fig. 24. After these operations an allowance is left for finishing the rotor.

After boring and turning of the shaft journals, the rotor blank is clamped in pot chucks; the outer diameter and the faces are checked for wobble, which must not exceed 0.03 mm. The rotor axis is centered at both ends (Fig. 24d); first the center is marked with a cutter and then a hole is made with a millimeter drill and counterbored with a 60° tool. A protective cone is made with a 120° counterbore. The drilling operation is carried out on a drilling machine with the aid of a jig or marked center.

Finishing of Rotors

The outer surface of the rotor, which is the basis of the final boring work, is ground on precision machines. The sequence of machining is shown in Fig. 25.

After centering the shaft, the rotor is mounted in the centers of a cylinder-and-cone grinding machine, which have been rubbed down and greased with industrial vaseline, and for some minutes, once the spindle has been engaged, the rotor runs idle to work in the centers. After this the outer diameter D'_3 of the rotor (Fig. 25a) is ground first

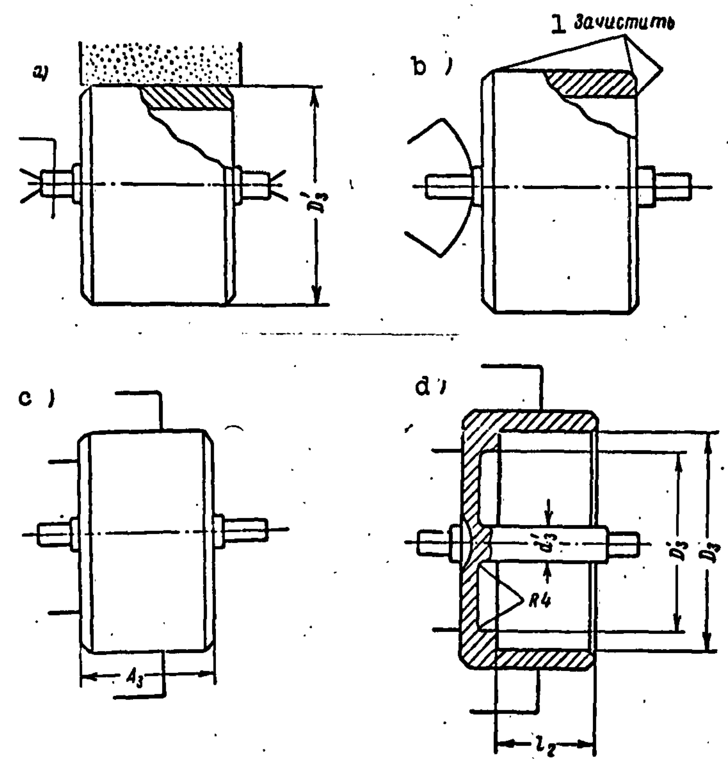


Fig. 25. Sequence of rotor finishing. 1) Emery cloth here.

rough and then finally with an allowance of 0.01 mm for final machining; an 8th degree roughness is ensured. Grinding is carried out with a medium-soft wheel with a grain grade of 60-80. Simultaneously with grinding of the outer surface, the rotor end on the bored end is also

finished to class 8 roughness without changing the length.

After grinding, the rotor is mounted on a lathe in a wire chuck on the journal (Fig. 25b) and the remaining sharp edges are cleaned with emery cloth. After this, the rotor is mounted by its inner bore on a special mandrel (Fig. 26). Before the rotor is set up on the mandrel, the wobble of its external diameter is checked; this must not exceed 0.015 mm. The rotor is clamped with thrust support (Fig. 25c) and the second end is spotfaced; holding to length A_3; leaving an allowance of 0.3 mm for finishing; the spotfacing roughness is of Class 5. A 60° chamfer is turned and the rotor is taken off. Then the rotor is mounted on the same mandrel (Fig. 25d), the wobble of the diameter D'_3 and the end is checked, and must not be greater than 0.01 mm; the rotor is clamped and the iron-pack bore is finish-turned on the diameter D_3 to a depth l_2, holding the beat of the bore and the face below 0.02 mm. The rotor bottom is finally spotfaced on diameter D'_3 with rounding, and the rotor shaft is turned inside the bore along the diameter d'_3. Boring and turning are carried out to the 6th finish class.

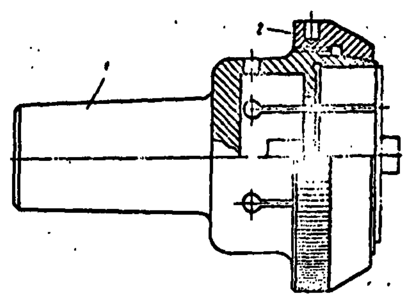


Fig. 26. Expansion mandrel for internal boring of rotor. 1) Mandrel with taper; 2) nut.

The finishing of the rotors, which ensures appropriate precision and roughness of the surface, has to be carried out on a lathe in top condition without excessive lash in the moving parts of the carriage, spindle and bearings in the radial and axial directions. For more exact reckoning of the cutter travel, lathes to be used for finish machining must be fitted with large-diameter circles to ensure the possibility of marking graduations on them for measuring diameters of the parts being processed with an accuracy of 0.02 mm. Finish machining of

certain rotor surfaces, such as the bores, ends, and shaft journals, is carried out on precision lathes by fine turning.

By "fine turning" we mean a finish-turning operation which is characterized by high cutting speeds, small cutting depths and feeds; this eliminates possible deformations of the parts being processed and of lathe units, and ensures high machining precision and finish.

Fine turning is done principally with lathes of massive and rigid construction in which the gaps in all rotating and traversing lathe units must be carefully adjusted and minimized. The spindle should be set in rotation by a V-belt or by a flat bonded (but not laced) belt to ensure that the lathe runs more smoothly. The cutters for fine turning are normally tipped with soldered hard-alloy plates of type T30K4 and T15K6 for machining steel parts and from T15K6 and VK6 for machining parts made of silumin. Diamond cutters have recently come into wide use.

The cutting depths for fine turning are between 0.05 mm and 0.3 mm and those for finishing operations between 0.05 mm and 0.15 mm. The feed during preliminary machining is in the range from 0.1 to 0.2 mm per revolution and during finish machining between 0.02 and 0.08 mm per revolution. The precision of the operation during fine turning in the diameter range 10 to 100 mm is characterized by the following figures: diametral tolerance from 0.005 to 0.008 mm; ovalness and taper in the range from 0.003 to 0.005 mm.

If the allowances are slightly increased the fine turning is carried out in two passes; in the first pass 70-75% of the total allowance is taken away.

The precision of the final fine-turning operations reaches the 1st or 2nd classes and the surface roughness is of the 7th-9th class. The fine-turning machining conditions are given in Table 8.

TABLE 8

Cutting Conditions for Fine Turning

1 Обрабатываемый материал	2 Инструмент из твердых сплавов	
	3 v м/мин	4 S мм/об
5 Алюминий	400—800*	0,03—0,10
6 Латунь Бронза	200—600*	0,03—0,10
7 Сталь конструкционная средней твердости	150—300	0,04—0,12

*Limited by the number of spindle revolutions.

1) Material being processed; 2) hard-alloy tools; 3) v, m/min; 4) S, mm/rev; 5) aluminum; 6) brass, bronze; 7) medium-hardness structural steel.

§25. MACHINING OF ROTORS WITH SHUNT WINDING

After final machining at the outer and inner rotor diameters, an iron packet with a shunt winding is pressed into it after machining at the outer diameter and along its length. Before pressing, preserving greases are carefully removed from the surfaces of the rotor and of the iron pack by rubbing them with a cleaning rag soaked in gasoline, rinsing in a gasoline bath and drying in air until all gasoline is removed; this is determined by the absence of the gasoline odor. The grease has to be removed completely from the iron pack of the rotor since grease remaining between the iron sheets is cause for rejection of the assembled gyromotor (see Chapter 4).

The cleaned rotors are placed in a thermostat on racks in separate batches where they are heated to 190-210° in 10-15 minutes. The heated rotors are taken out separately and mounted in a special base. The iron pack with the shunt winding is pressed into the bore of the rotor as far as it will go, basing it on its inner diameter with a special bushing. One of the devices for pressing is shown in Fig. 27. After pressing the iron pack with shunt winding into the rotor, the

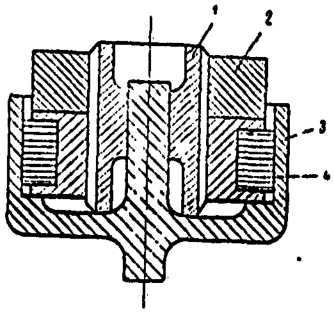


Fig. 27. Fixture for pressing iron pack into rotor. 1) Sleeve; 2) false ring; 3) flywheel; 4) rotor iron pack with shunt winding.

unit is cooled in air down to the temperature of the surrounding medium. After the quality of pressing has been checked, the unit undergoes further machining.

During final turning after pressing, the rotor is mounted by its outer ground surface on a mandrel (Fig. 26) [sic] with the open end toward the spindle. Before machining a batch of rotors, the mandrel, mounted in the lathe spindle, is bored out to the mean outer diameter of the batch of rotors, to ensure reliable mounting for each rotor. On mounting, the rotor is based on its face, secured with a nut on the mandrel and is machined in the sequence shown in Fig. 28.

First the open end of the shaft (Fig. 28a) is machined, the journals being turned along the diameter <u>d</u> for the ball bearing with a grinding allowance of 0.1 to 0.15 mm. The end is cut simultaneously, keeping h_1 with a maximum radius of 0.2 mm at the fillet. Then the rest of the shaft between the fillet of the journal and the rotor end is turned along d_1 and the end of the shaft turned along d' for threading. The nut is released and the rotor taken out, mounted from the other side in the same mandrel and secured with the nut; the second journal of the axis is turned along diameter <u>d</u> with an allowance for the ball-bearing seat; the end of the journal is spotfaced with a radius of 0.2 mm, holding the distance H between the ball-bearings and leaving an allowance of 0.07-0.13 mm for grinding the ends. Then the second end of the shaft is turned on d' for threading. In the same mandrel, a special groove cutter is used, first on one end and then on the other, to turn a groove with a width of 1.2 mm and a depth of 0.5

mm for pulling out the thread-cutting tool; care is taken that the length of the ball-bearing journal is not altered (Fig. 28b). In the same mandrel an M4 thread is cut on one end of the rotor shaft with a special thread-cutter; then the rotor is turned around in the mandrel, and a thread is cut on the other end of the shaft after removing the chamfers. On the open end of the rotor the journal is given the 60° chamfer necessary for clamping the inner ball-bearing ring with a puller. A 10° taper is turned on the end of the rotor rim.

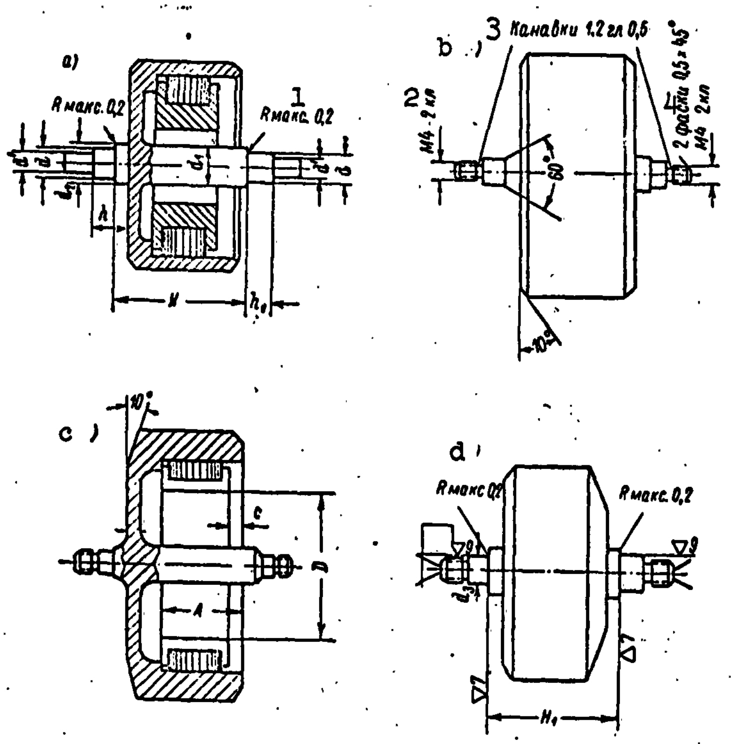


Fig. 28. Sequence of final machining of the rotor. 1) Max; 2) class 2; 3) grooves, 1.2 × × depth 0.5; 4) chamfers.

The next operation, one of the critical ones, is final boring of the iron pack with the shunt winding for the stator iron pack, ensuring the necessary uniform air gap between rotor and stator, which determines the main electrical parameters of the gyromotor. For boring, the rotor is mounted in the mandrel shown in Fig. 26, with its rear

end toward the spindle. Before the mandrel is secured in the spindle, the latter is checked using an indicator with a scale-division value of 1-2 μ; the pulsation of the mandrel must not exceed 0.003 mm. The pulsation of the rotor mounted in the chuck is also checked at its outer diameter and at its end; the pulsation must not exceed 0.005 mm. After adjusting to this degree, the rotor is fixed with the mandrel nut. In two or three passes the inner diameter D is bored for the length ... (Fig. 28c) of the iron pack. In boring, diameter D should be kept to a class 2 tolerance and the bore should be perpendicular to the rotor axis along A with an accuracy of 0.008 mm. The roughness should not be lower than class 6; clogging with metal must not occur between neighboring plates since this may connect the separate plates, thus causing additional eddy-current losses to arise in the rotor iron pack. After boring of the iron pack, the end of the shunt winding is bored and spotfaced, keeping a distance C from the end of the rim. After this a facet is turned on the end of the winding with a 1.5-mm radius on the whole diameter allowing free access for inserting the stator iron pack into the bore during assembly of the gyromotor. The second edge of the winding is also rounded from the inside in the middle of the bore. Based on the end, the rotor is mounted in a prebored pot chuck and the second cone of the rotor is turned at an angle of

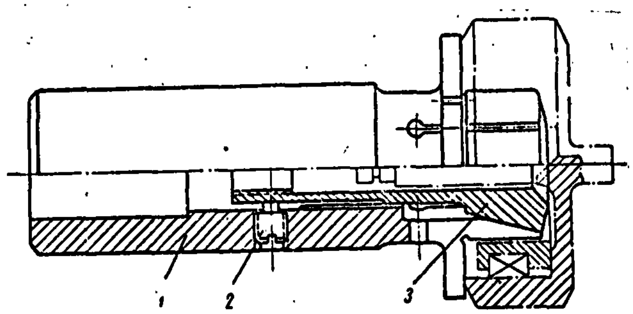


Fig. 29. Expansion mandrel. 1) Mandrel; 2) screw; 3) expansion collet.

10^{o}, with a surface roughness of class 7. The finally turned rotor is mounted on a mandrel (Fig. 29) by its inner bore, and the edges on the outer diameter are rounded with a radius cutter with the bore at an angle; then the whole outer surface is cleaned with emery cloth with an 80-160 grain, ensuring a surface roughness of the 7th finish class.

Final Grinding of the Rotor

After turning, the rotor undergoes final machining (grinding) of the ball-bearing seats.

In this final machining of the ball-bearing seats, high precision on the outer diameter and a high degree of finish have to be ensured. Precision and roughness of surfaces finished by grinding depend on many factors. The most important are:

– the characteristics of the grinding wheel, especially its grain size;

– the cutting formula – the peripheral velocity of the grinding wheel, the peripheral velocity of the part, the amount of longitudinal feed and the cutting depth;

– the quality of dressing of the grinding wheel;

– the condition of the machine and its dynamic rigidity;

– the balancing of the grinding wheel;

– the condition of the machine centers and of the centering holes in the part;

– the method used in the passes of the grinding wheel over the machined surface;

– the physicomechanical properties of the rotor material being processed.

The higher the demand for surface roughness and accuracy of dimensions, and the greater the hardness of the rotor material, the more fine-grained must the grinding wheel be. When a rotor made of 35KhMYuA

steel is finish-machined, an EKB 60-120 SM_1-SM_2 grinding wheel is normally used.

When the peripheral velocity of the grinding wheel is increased, the roughness of the machined surface decreases, while with increased cutting depth and peripheral velocity of the part it increases.

To obtain the necessary precision and roughness of the surfaces being machined, the grinding wheels have to be carefully trued with a diamond, and before mounting they should be balanced. A particular influence on the roughness of the surface being machined and on the precision is exerted by the condition of the machine centers and the centering holes in the rotors, which are the positioning bases.

During final grinding of the journals and their ends a nut is screwed onto the thread of the shaft, the centering holes are rubbed carefully with a pointed wooden stick and greased with industrial vaseline, and the rotor is mounted in the centers of the machine. The wobble, which is checked on the outer diameter and the end, should not exceed 0.01 mm. Before grinding, the centers are worked in by running the machine spindle, with the rotor, easy for several minutes; then one journal is ground, the rotor is turned around and the other journal is ground. The journals are ground with radial feed (plunge grinding). Longitudinal shifts of the grinding wheel do not occur, since its width encompasses the whole length of the journal being machined. The radial feed of the grinding wheel is in the range of 0.002 mm per revolution of the journal. The journals are ground finally along the diameter (Fig. 28d) to Class 1 precision with tolerances of 2 to 3 μ and to a surface roughness of Class 9; simultaneously the end of the journal is also ground, forming a fillet with a radius no greater than 0.2 mm. Then the back center is released, the rotor is taken out of the centers, and the nut is screwed on the thread at the other end of the

shaft; the rotor is set up again in the centers, the wobble of the outer diameter and end is checked and the second journal and its end are ground, holding the radius of the fillet and the dimension H_1 between the ends of the journals.

The surface roughness of the ends of the journals is guaranteed to the 7th class. Special attention should be paid to the precision of the fillet radii and the journal ends. The journal ends must be machined strictly perpendicular to the seat diameter d_3 of the journals. The perpendicularity of the journal ends is of great importance, since they locate the inner rings of the ball-bearings pressed to them. The ring ends have a perpendicular position in relation to the rotor axis only if the journal ends are machined strictly perpendicular to the axis.

The perpendicularity of the journals is ensured by dressing the end of the grinding wheel exactly perpendicular to its generatrix since the journal ends are face-ground with the same grinding wheel used on the radial diameter of the journal.

When the journal ends are ground it is necessary exactly to maintain the radii of the fillets since an incorrectly machined chamfer can be the cause of abnormal running and premature failure of the ball bearings, and may sometimes make it impossible to balance the rotor dynamically.

The radius of the fillet should always be somewhat smaller than the radius of the chamfer of the inner ball-bearing ring. The required radius of the fillet is obtained by rounding the corner of the grinding wheel to the same radius when it is diamond-dressed. When the grinding wheel corner is dressed to a radius greater than the radius of the chamfer of the inner ball-bearing ring, then the fillet is machined with a greater radius with the result that the inner ring is

not pressed to the end of the journal axis in assembly, and the ball bearing may be skewed. If the inner ring is not positioned correctly the ball bearing cannot work normally and it is almost impossible to obtain exact dynamic balance for the rotor.

During the series production of gyromotors in one of the plants an error in the routine dressing of the grinding-wheel corner was permitted (the radius was made greater than that of the chamfer of the inner ball-bearing ring). Consequently, it was impossible to balance the rotor dynamically with the specified accuracy. Only on measuring the fillet radii with a comparator was it possible to discover the manufacturing imprecision. After correction of the radii in correspondence with the drawing all rotors were balanced dynamically with the necessary accuracy.

After grinding the journals, the rotors undergo polishing; rotors with grooves in the threaded part of the journal are first grooved on a milling machine by means of a special mushroom-shaped cutter, burrs formed on the thread are removed, the thread vanish is trimmed by filing the sharp edges, and the rotors are sent for polishing.

The outer surface of the rotors is ground on high-speed lathe-type finishing machines with the rotor mounted in the stator bore on a special mandrel (Fig. 30). Special protective cap nuts 1 are screwed onto the journal thread. First the whole rotor surface is deburred rough with emery cloth with a grain grade of 80-100, then finally with emery cloth with a grain of 120-160; a surface roughness of Class 8-9 is obtained. After cleaning, the whole surface of the rotor is polished with cotton or felt strips.

The polished rotors are taken to the finishing shop for application of an anticorrosive coating (see Chapter 4) and after this they come back to the machine shop for lapping the journals before dynamic

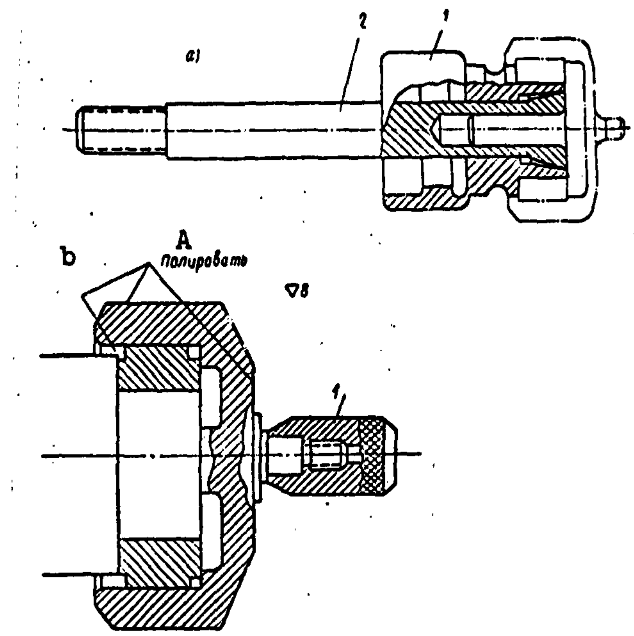


Fig. 30. Mandrel for polishing rotors. 1) Nut; 2) tapered mandrel. A) Polish here.

balancing.

§26. PRECISION-SIZING OF ROTOR JOURNALS

The last operations of machine finishing of rotors is precision-sizing of the ball-bearing seats on the journals of the axis. Rotors ready for precision-sizing are completely machined and covered inside and outside with an anticorrosion coating. Along with the accompanying documents of the rotors, tables listing the precision-sizing dimensions, drawn up on the basis of the dimensions obtained in measuring the bores of the inner ball-bearing rings is given to the machinist. The boring dimensions are measured by the methods and instruments described in Chapter 5, or are supplied by the ball-bearing factory. In the table the mean dimensions are given to within 2 μ, i.e., all dimensions obtained having a deviation within the limit of 2 μ are combined in one mean dimension. The number of journals whose diameter has to be precision-sized to each dimension is given. The journals are brought

to dimensions which ensure interference at the tension indicated on the drawing when the inner ring of the ball bearing is placed on them. It has been shown by experience and by calculations that a negative clearance of 1 μ produces a force of 3 kg, one of 2 μ a force of 9 kg, one of 3 μ a force of 27 kg, and so on (tapering and ovalness are included in the interference).

Precision-sizing of the journals is carried out with special precision-sizing machines or with lathe-type finishing machines; the aim is to obtain higher-precision dimensions and geometric shapes, to raise the quality and lower the roughness of the ground journal surfaces.

The quality of the journal surface is increased during precision-sizing by the removal of ridges and of the metal layer softened during grinding. It has to be taken into account that during precision-sizing little time is necessary to remove ridges only. The time necessary for removal of the rest of the allowance increases considerably since metal has to be taken away from the whole surface. Therefore it is necessary to strive for maximum accuracy of the journal dimensions in the grinding so that during precision-sizing only that layer of metal has to be removed which is equal to the height of the ridges, to improve the geometric form and to remove the softened surface layer.

Precision-sizing is carried out with laps to whose surfaces a fine abrasive material or strips cut from special rouged papers are applied. In the precision-sizing process, relative motion between the lap and the journal mechanically removes metal particles from the journal surface of the shaft. To obtain the exact form of the journal surface to be sized, proper movement of the lap in relation to the surface and the shape and material of the lap are very important.

High precision-sizing quality is achieved with a continuous con-

tact and the greatest possible zone of contact of the lapped surfaces; hence the basic form of relative motion during precision-sizing of journals should be rolling with a simultaneous gliding in relation to the lap. For uniform removal of the allowance it is necessary that all points of the lapped surface move in relation to the lap with a uniform speed. Flat laps are made slightly wider than the journal neck and ring-shaped ones have holes larger than the journal diameter. Flat and ring-shaped laps execute a reciprocating motion, and the journal rotates. For this purpose, a cap nut is screwed onto the thread of one of the journals, and the rotor is mounted in the centers of the machine.

§27. MACHINING OF THE HOUSINGS

High demands are set as to coaxiality of the cover seating diameter and ball-bearing bores in the gyromotor housings. The radial and end wobble of the body surfaces with respect to the ball-bearing bores should not exceed 0.01 mm. The locking surfaces and the seat for ball bearings should have tolerances of 1st and 2nd precision class. Gyromotor housings differ from each other on the outside by the cast bosses for the journals and in the methods of mounting of the cover. The basic machining operations of different housings made of silumin are nearly the same.

Let us consider the machining of the housing shown in Fig. 8a. The sequence of machining of this housing is shown diagrammatically in Fig. 31.

The first operation of machining the housing is normally machining of a base surface; for this purpose a mandrel is mounted on a lathe spindle (Fig. 32). The pulsation of the mandrel taper is checked, and must not exceed 0.05 mm. The housing is mounted on the mandrel taper by its bore and clamped so that the rotating center rests in the boss hole of the ball-bearing seat formed in casting (Fig. 31a). First the

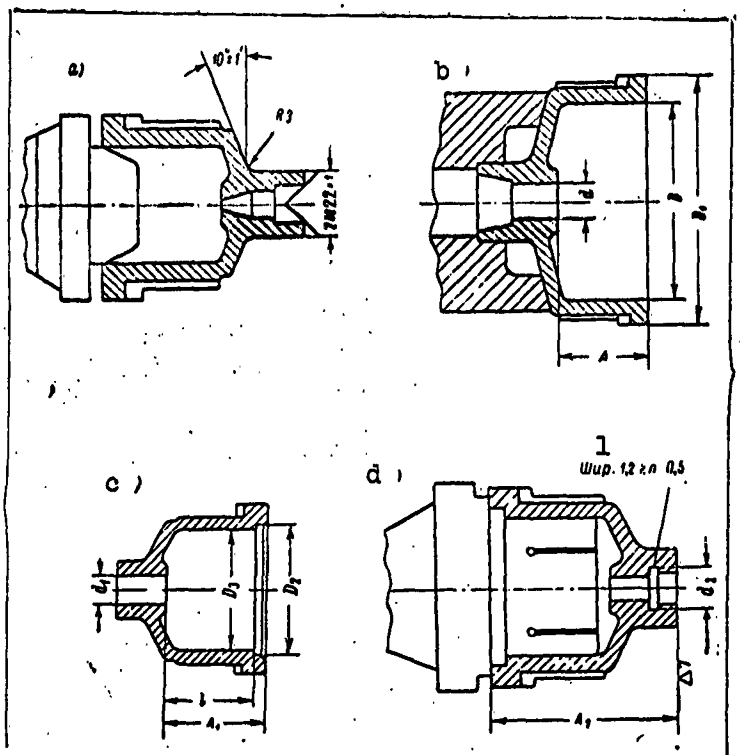


Fig. 31. Sequence of housing machining. 1) width.

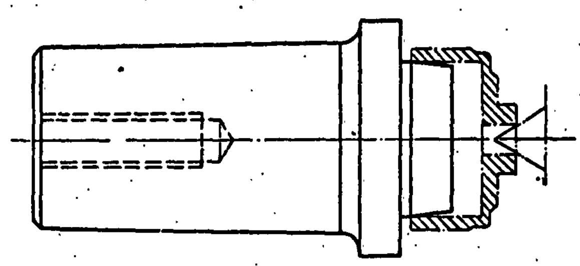


Fig. 32. Mandrel for machining the base surface of the housing.

housing end is turned clean at an angle of 10° by a radius cutter, holding the housing wall to the specified thickness; then the radius transition is turned from the housing wall to the outer surface of the boss. The housing face is the base for all further machining. On the outer elongated surface of the boss, which served as a special overflow reservoir in casting, a technical thread is cut by means of which the housing is mounted during further machining. All sharp edges

formed in machining are blunted by a scraper.

The housing is bored on a mandrel (Fig. 33) mounted by its taper in a lathe spindle with a wobble not exceeding 0.05 mm. The housing is screwed into the mandrel thread by means of the technical thread cut on the surface of the boss, until the outer housing base surface makes contact. First the bore with diameter D is bored rough (Fig. 31b) by a radius cutter, with an allowance of 0.2 to 0.3 mm for further machining. The end of the rear housing wall is machined (if the wall thickness was not kept to in casting) and the radius of the rounded passage to the boss face is turned; the surface roughness is held to Class 5. After this, the ball-bearing bore d is turned rough with an allowance of 0.02 mm on the diameter for final machining. The housing face is machined, holding the dimension A from the face of the inner boss, and the housing rim is turned on the outside diameter D_1 along the whole length, holding to the specified height and outer diameter.

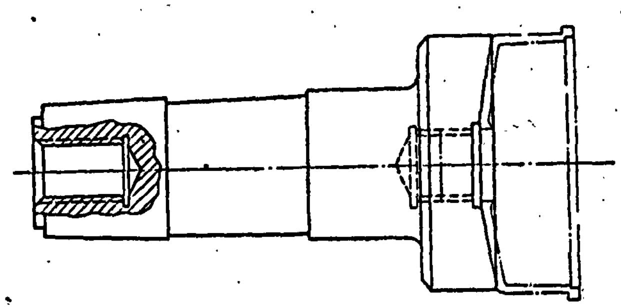


Fig. 33. Mandrel for machining inner housing surfaces.

The final boring of the housing is carried out with a mandrel of the same type, mounted in a lathe spindle with a wobble not exceeding 0.01 mm. The technical thread is used to mount the housing against the machined face in the mandrel thread and the inner face of the boss (Fig. 31c) is spotfaced, the bore in the housing is finish-turned, holding to diameter D_3, to a depth A_1. The cover joint in the housing

face is bored to a diameter D_2. The face of the boss is spotfaced finally to a length l from the joint end, and the bore for the outer ball-bearing ring is finally bored through. Boring is carried out with a boring cutter to first-class precision with Π_1 fit in two passes at a feed of 0.02-0.1 mm/rev and a cutting speed of 500-600 m/min. Ovalness and taper of the ball-bearing bores are checked selectively, as is sometimes done with all parts, using an optimeter.

In some plants pneumatic instruments are used for examination of ball-bearing seats to check the boring work. The basis of these instruments is a contactless measuring method (Fig. 34a) which consists in the following.

Compressed air is forced into the tube 1, which is submerged in water. In the tube and in the container joined to it an air pressure H corresponding to the submersion depth is established (usually the submersion depth is 500 mm).

The air is passed at constant pressure through tube 2 into the chamber 5 through an inlet nozzle and flexible hose 3 to the measuring nozzle 4. A manometer 6 is connected to the chamber. The manometer dial is graduated in microns. The pressure variation is proportional to variations of the air gap between the measuring nozzle and the part to be measured. To facilitate the reading the water is slightly colored. The water level should be kept constant. The air, compressed to a pressure of 0.5-2 atm, is blown through a dust catcher.

Figure 34b shows a diagram of a pneumatic gage for measuring bore diameters. The gage, with a central air line, has two nozzles 1. The diameter of the gage is smaller than the minimum diameter of the hole to be checked. The measuring nozzle does not touch the hole wall; this prevents premature wear to the pneumatic gage. The instrument ensures contactless measurement of linear dimensions with shape deviations

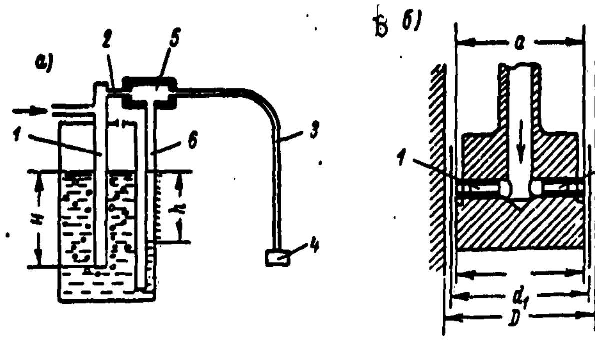


Fig. 34. Pneumatic measuring device (a). Pneumatic gage (b). 1) Tube; 2) inlet nozzle; 3) flexible hose; 4) measuring nozzle; 5) chamber; 6) manometer.

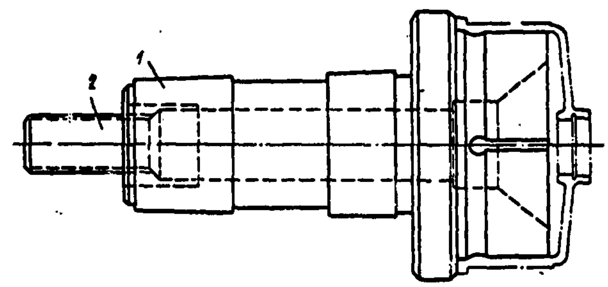


Fig. 35. Mandrel for outside machining of housing and thread cutting. 1) Mandrel; 2) rod.

(ovalness, taper) with an accuracy of 0.4-0.5 μ. Outer ball-bearing ring bores of housings and covers can be measured immediately with such gages during boring on the machine or during inspection of finally machined housings and covers.

Ovalness and taper of outer ball-bearing ring borings should be within half of the diametral tolerance; the radial and end wobble of the lock surfaces should not be greater than 0.01 mm; the surface roughness should be of the 6th to 7th class.

After final boring, the housing is mounted in an expanding mandrel (Fig. 35), which is mounted in a lathe spindle with a wobble of the base surfaces smaller than 0.002 mm on the outside diameter and base. The housing is mandrel-mounted by the notch for the cover lock

and is fastened by tightening the expansion taper of the mandrel through the lathe spindle. When the housing is mounted, the wobble of the ball-bearing bore and the lock face is checked; it must not exceed 0.004 mm.

Once the housing is mounted, the technical thread on the tailpiece is cut off and spotfacing used to maintain the height dimension A_2 on the housing (Fig. 31d), with a surface roughness of class 7. Then the bore d_2 of the thread boss for the ball-bearing nut is bored and a groove 1.2 mm wide and 0.5 mm deep cut for withdrawing the thread-cutting tool, without disturbing the ball-bearing dimension. Finally, the boss is bored for its outside diameter if the dimension was not held to in casting, and a thread for the bearing nut is cut inside the boss. The thread must be cut in such a way that its radial wobble relative to the bore for the ball bearing will not exceed 0.05 mm. Here the surface roughness should not be lower than the fifth class and no stripped fibers should be in the threads.

§28. BORING JOURNAL HOLES IN HOUSINGS

After final lathing, lateral holes positioned at angles of 180° are bored to accommodate the pins for mounting the gyromotor in the gyroscope's gimbal during assembly. These critical holes are bored on precision lathes or special composite machines.

Before boring for the pins, holes are first jig-drilled on a drilling machine to ensure a dimension with an allowance for boring, coaxiality of the holes, and the technological dimension from the face of the housing shoulder to the holes.

The rough-drilled holes for the pins in the housings are bored out on a lathe using a special fixture (Fig. 36) consisting of a mandrel 1 (Fig. 36a) with a taper that is precision-fitted to the tapered hole in the machine's spindle. On the opposite end from the taper, the

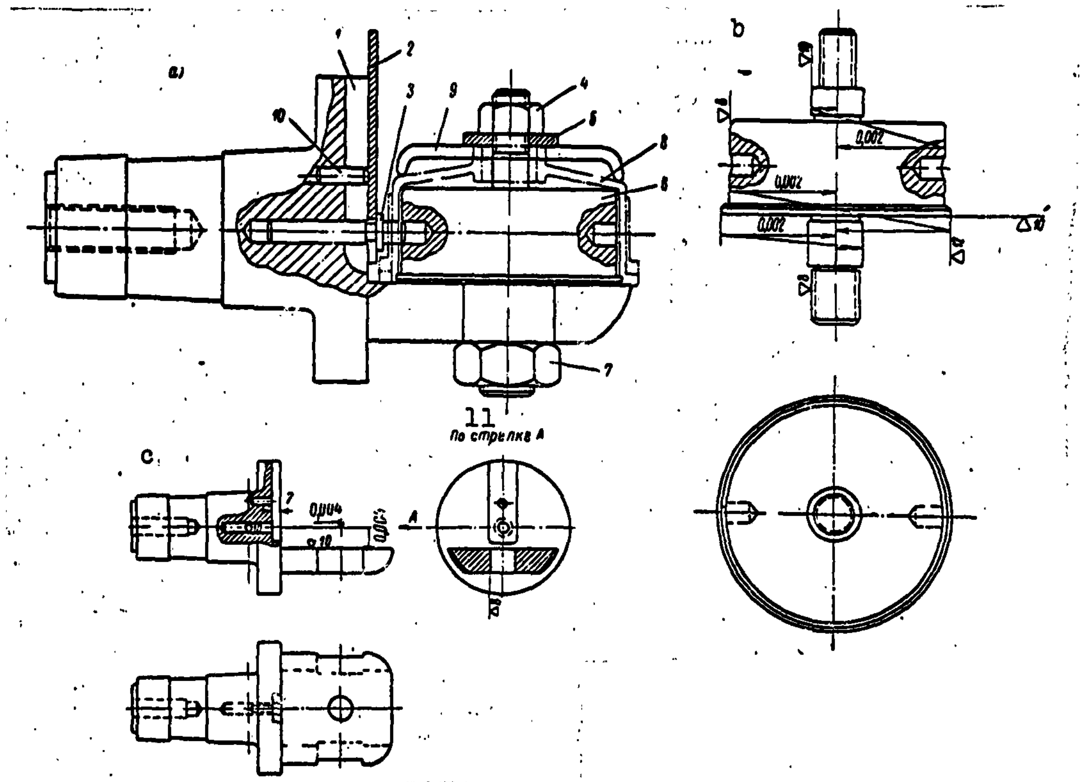


Fig. 36. Fixture for boring journal holes (a). Mandrel (b). Locator (c). 1) Mandrel; 2) yoke; 3 and 6) locators; 4 and 7) nuts; 5) washer; 8) gyromotor housing; 9) clamp; 10) locating pin; 11) seen along A.

mandrel has a platform situated at the exact distance from the center of the mandrel corresponding to the housing dimension with the appropriate tolerances from the face of the shoulder to the axis of the holes for the pins. In the center of the mandrel, a hole is drilled for the pin of locator 3 and brought to a surface roughness of class 10; the deviation of its axis from parallelism to the finished platform must be no greater than 0.004 mm. The center of the platform has a 90° trued hole in which the housing locator pin is fixed (Fig. 36b). The locator is machined from a one-piece blank and has locating seating areas precision-machined to the dimensions of the housing, as follows: the lock bore, the housing bore and the hole for the ball bear-

ing. The wobble of the individual seating surfaces is held within 0.002 mm in fabrication. The locator on the mandrel platform is secured by a press fit of the neck into the hole of the mandrel and the nut 7.

In boring the holes for the pins, the housing is set up on the locator by the lock recess, the bore and the ball-bearing hole, and the face surface of the rim is applied tightly to the surface of the mandrel serving as the base. A clamp whose ends rest against the outer surface of the housing above the cylindrical part is pressed from the top down onto the threaded part of the locator and secured to the mandrel by the nut 4. Adjustment and rotation of the housing with its rough-drilled holes through exactly 180° are provided for by insertion of a center, held in the tailstock and rigorously coaxial with the spindle, into the housing hole facing the machine's tailstock in the setup. The housing is turned by hand on the locator in such a way that the center is sunk all the way into the hole, and the housing is secured on the fixture in this position by tensioning it with nut 4 against the plane of the mandrel. Then the tailstock with the center is pulled out of the housing and the face of the housing boss spot-faced, maintaining the dimension from the center of the housing; the axis holes are bored to precision class 2 and finish class 7. The housing is released by backing off the nut 4 and then turned through 180° on the locator. Positive location is ensured when the housing is rotated by tight insertion of the locator into the bored housing hole with the yoke 2; only after this is done is the housing again secured on the fixture with the nut 4. The other boss on the housing is spot-faced, holding the dimension from the housing center to the bore, and the second axis-pin hole is bored out. When the axis-pin holes are bored on such a fixture, coaxiality is ensured to within 0.005 mm and perpendicularity of the hole axes to the housing axis is within 0.01 mm.

on a length of 100 mm.

Drilling Holes on Gang Machine

At certain plants, the axis-pin holes in gyromotor housings are bored on gang machines, which deliver considerably more of the required precision than do lathes. The operation is performed on the same machines with two or four heads used to bore the holes in the gimbals of gyroscopic instruments.

The ganged machine (Fig. 37) consists of a welded-up pedestal on which is mounted a framework casting with holes for special heads situated 90° apart in the case of four of them. To bore the holes for the axis pins in the gyromotor housing, the ganged machine may have only two heads situated at an angle of 180°. The heads are inserted into the holes in the cast housing, so that precision positioning is achieved. The heads are usually equipped with separate electric motors, and their spindles are driven by V-belt.

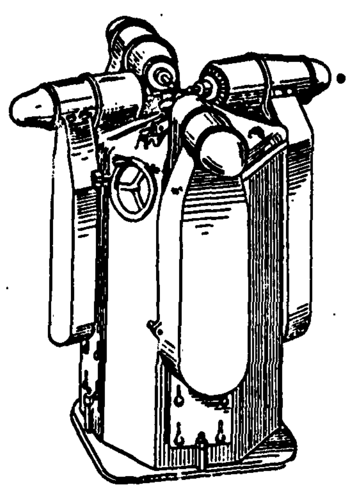


Fig. 37. Ganged machine tool.

Figure 38 shows a diagram of sequential hole drilling of a housing for axle pins using a two-head ganged machine.

The gyromotor housing is set up on the locator (Fig. 36b), which is secured in a vertical turntable with a vernier scale. The appropriate cutting tools are set up in the head spindles. Usually, a drill for rough drilling of the hole and a spotfacing tool for the boss are set up in the spindle of the first head. The second-head spindle holds the boring tool and, for final spotfacing of the boss, a spotfacing cutter.

The boss is spotfaced and the hole drilled by the following pro-

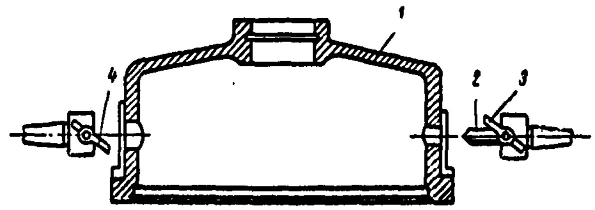


Fig. 38. Diagram illustrating boring of axis-pin holes on ganged machine with two heads. 1) Gyromotor housing; 2) flat drill; 3) spotfacing tool; 4) boring tool.

cedure: feeding the first-head spindle toward the housing, the drill makes a hole and the spotfacing cutter performs a rough operation on the boss face. When the drill has pierced the housing and the boss has been spotfaced, the machine table with the locator on which the housing is secured is turned through 180°, the hole for the axle pin is finish-bored by the boring tool secured in the second head, and the face of the boss is given its final spotfacing, holding to the specified dimension from the housing axis to the plane on which the pins are to be secured. During this time, the first head drills the second hole and does the preliminary spotfacing job on its boss. The final boring operation is done on the second hole and its boss given the final spotfacing by the second head after the machine table is indexed again.

The coaxiality of the axle-pin holes is checked with an indicator with special plug gauges that are held in centers and fit into the holes (Fig. 39). These plug gauges, which have centering holes, are strictly coaxial with the seating diameters. Usually a set of plugs is made with a 0.005-mm diameter step for each hole, since this facilitates matching of the plugs to the holes, the diameters of which may vary within the tolerance. The plugs are selected to push-fit. To make the check, the housing is turned about the axis of the centers and the plug wobble checked on one end; then the indicator foot is set up on

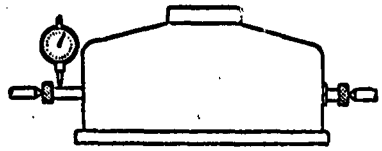


Fig. 39. Diagram showing inspection for coaxiality of two opposed holes for axle pins.

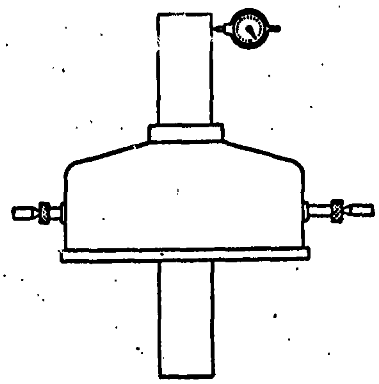


Fig. 40. Diagram showing inspection for perpendicularity of axle-pin holes to ball-bearing bore.

the other plug and its wobble is measured. The difference between the wobbles with the axis of rotation in coincidence will be a measure of the departure of the axle-pin holes from coaxiality.

The perpendicularity of the holes with respect to the housing axis is checked in centers with special plugs that are inserted into the bored holes and a smooth precision mandrel inserted into the ball-bearing bore of the housing (Fig. 40). With the plugs, the housing is set up in centers and the indicator foot is applied to the mandrel at a distance of 100 mm from the cover end and then from the housing end, and the deviation is noted from the indicator needle.

The placement of the holes must be checked carefully the first time. If repeated measurements are necessary, the mandrel must again be push-fitted into the holes, and after two or three measurements, this may take the dimensions of the holes outside the tolerances, since the housing is usually made from silumin – a relatively soft material – and the holes are easily enlarged in size when a measuring tool is push-fitted into them.

The next operations in the production process of manufacturing the housings is drilling the holes and cutting the threads. The precision with which the holes are located in jig-drilling depends on the precision with which the holes or bushings are located relative to one another and the base in the jig. First the holes are jig-drilled through

the bosses for mounting the threaded axis pins. Then jigs are again used to drill the inspection windows in the bottom of the housing, the holes in the face of the housing that are to be threaded for bolting the cover to the housing, and the holes for attachment of the nameplate. Drilling is followed by counterboring and tapping the thread. The threads must be cut with ground or specially precision-finished taps to precision class 2. The thread must be clean, without stripped turns, and the sizing tool should screw in to full depth tightly and with constant effort. The precision of the thread is influenced by the total torque, the skew of the tap axis with respect to the axis of the hole to be threaded, and the wobble and deformation of the tap. To obtain the proper dimensions on inside threads, it is necessary to drill the diameter of the threading hole somewhat larger (the drill size is given on the production process sheet) than the minor diameter of the thread. As is indicated in Chapter 6, the stability of the axial interference in the gyromotor depends on the quality of the thread made in the housing to mount the cover.

After the burrs have been removed and the thread has been washed and quality-controlled, the housings are sent to the shop for application of an anticorrosion coating (anodizing), as described in Chapter 4.

§29. MACHINING AXIS PINS WITH HOUSING

The nameplate rivets are headed before the axis pins are secured to the housing. Prior to this operation, the pins are thoroughly degreased by rubbing with a gasoline-soaked rag and the bearing seats are greased with TsIATIM-202 anticorrosion lubricant. The seating areas in the housing are degreased, again by rubbing them with a gasoline-soaked rag; then the axis pins are inserted with their short shanks in the bored holes of the housing and the faces of their flanges in the recesses of the housing bosses. This double location of the axis pins

in the housing — at the shanks and at the flange faces, which can be machined in a single setup — ensures that they will be perpendicular and, consequently, that the gyromotor will be precision-installed in the gyroscope's gimbal suspension. When the pins are inserted and the holes aligned for assembly, a single drop of nitro enamel is placed in the thread of each hole in the housing to prevent self-unscrewing; then, without tensioning, the screws are turned into the threaded housing holes through the open counterbored holes in the axis-pin flange. The screws are tightened gradually with application of uniform effort; it is necessary to take care that the slots in the screw heads are not mutilated. Care must also be taken to see that the screws do not project into the interior of the housing, since otherwise they might jam the rotating rotor.

When the pins have been secured, the cover is fitted to the housing; it should seat on the housing lock by hand with only slight interference. A smooth mandrel is inserted into the ball-bearing holes of the housing and cover and the perpendicularity of these holes is verified in centers (Fig. 41); this should lie within 0.05 mm on a length of 100 mm. The mandrel must push-fit into the housing and cover holes but it should not require a major effort. If perpendicularity is not maintained, a second cover is tried, and this continues until perpendicularity within the tolerance is assured. The cover that has been matched to a housing as regards lock and coaxiality of the ball-bearing receptacles may not be replaced by another, either in machining operations or in assembly of the gyromotor. The number of the gyromotor, which is punched onto the nameplate before the latter is secured to the housing, is tagged on the cover with indelible paint or a metallic sticker. The cover is coupled freely to the housing with a special bolt that passes through the holes for the ball bearings in the hous-

ing and cover, and the housing is ground with the axis pins in this form.

Before grinding, a collar is placed on one of the axis pins and tightened, the centering holes are lubricated, and then the housing with its pins is placed in the centers of a machine and the pins spun for several minutes. First one axis-pin neck is rough-ground with an allowance of 0.05 to 0.06 mm for final grinding, and then the housing is reversed in the centers and the neck ground on the second pin, in a preliminary operation with the same allowance. The same procedure is used in final grinding of the necks and face ends of the axis pins, holding the dimensions of the bearing seats to the first precision class and ensuring face wobble within 0.005 mm and the specified dimension between the faces of the pin necks with a surface roughness of class 7. The deviation of the necks from coaxiality after grinding should be no greater than 0.01 mm, and the wobble of their surfaces should not exceed 0.02 mm.

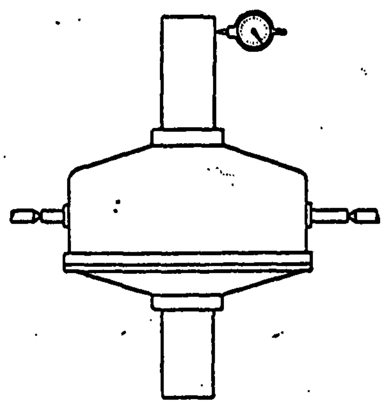


Fig. 41. Diagram showing inspection for perpendicularity of axis pins to housing and cover axis.

Like the rotor journals, the pins are ground on high-precision cylindrical grinding machines with abundant cooling. The grinding wheel used has a grain rating of 60-120. Pins that are longer than the grinding wheel is wide are ground by the traverse-feed method; here, the crossfeed during each longitudinal pass of the table ranges from 0.005 to 0.007 mm. The last passes incorporate the so-called "pruning" or finishing operation on the axis-pin surface being ground; this consists of a series of finishing passes without feed in depth, which assists in reducing the roughness of the machined surface and raising

machining precision.

After the housing pins have been ground and before they are stacked in intermediate storage, they are sent to have the pins treated with a preserving agent, a process described in Chapter 4.

§30. MACHINING OF COVERS

As in the case of the housings, rigid specifications are set forth for the covers as regards coaxiality of the lock groove and the ball-bearing bores. The radial and end wobble of the lock with respect to the ball-bearing hole may not exceed 0.01 mm.

Meeting the rigid tolerances for the linear dimensions and the admissible wobble level presents considerable difficulty, since in most cases the covers are cast from silumin and are not adequately rigid. For this reason, special conditions must be observed in machining and shipping them.

Since there are only minor differences between the designs of various gyromotor covers, we shall consider as our example the machining procedure for the cover shown in Fig. 8a. The machining sequence is schematically represented in Fig. 42.

When the flash has been removed from the castings and they have been aged under the conditions described in Chapter 2, the covers are machined on high-speed high-precision machines. The first lathing operation is carried out with the use of a mandrel (Fig. 42a) set up in the machine spindle. The cover is placed on the mandrel by its inner surface and pressed by a live center inserted in the boss hole until it stops against the face. The face of the outer cover surface is spot-faced clean from diameter D to D_1 and turned through on the diameter $\underline{d}$ of the boss and the outside diameter D_1 of the cover. Then the expanding mandrel (Fig. 43) is set up in the machine spindle, the cover is pushed onto it until it comes to stop against the surface that has pre-

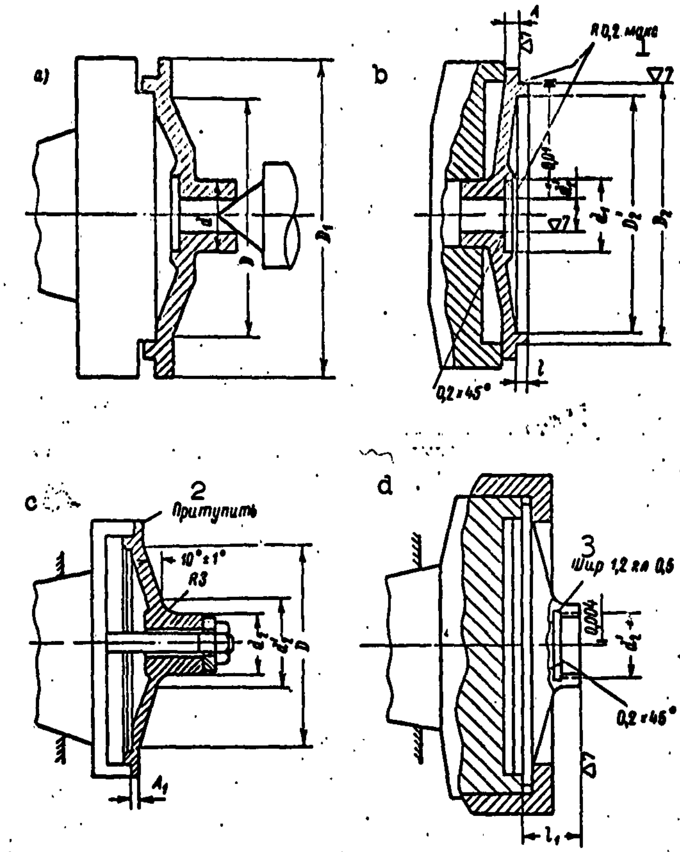


Fig. 42. Sequence of cover machining. 1) Maximum; 2) round off; 3) width.

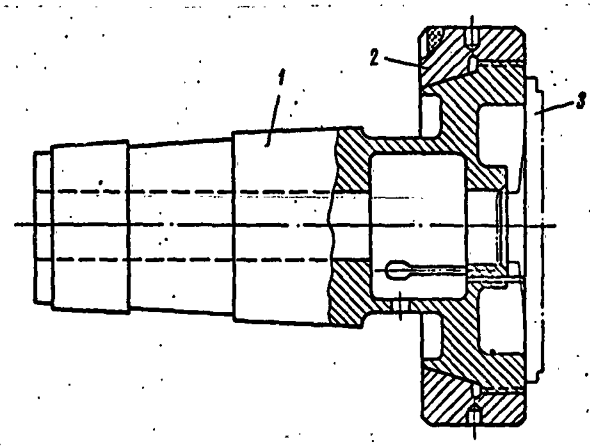


Fig. 43. Mandrel for boring ball-bearing holes and lock in cover. 1) Expansion mandrel; 2) nut; 3) cover.

viously been turned, and the mandrel nut turned to force in the outside preturned diameter of the boss. The diameter D_2 of the cover is given the final turning operation for the lock (Fig. 42b), holding to the thickness A of the bead by providing the necessary radius. Then the lock is spotfaced, maintaining the height l, and the inside notch of the cover bored out from diameter D'_2 to the depth of the bead. The boss is spotfaced and bored on diameter d_1 to precision class 2 for the stator bushing; finally, the bore d'_1 for the ball bearing is through-drilled in a finishing operation to class 1 with a P_1 fit. The bore for the ball bearing and the ground surface of the lock must be made to finish class 7, and all other surfaces to class 6. Sharp edges must be rounded off and a $0.2 \times 45^{\circ}$ chamfer must be removed from the ball-bearing bore in the boss.

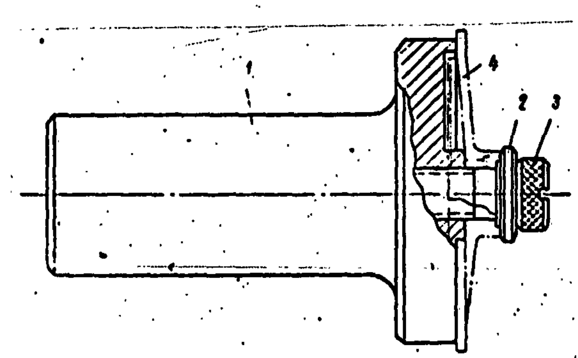


Fig. 44. Mandrel for outside machining of cover. 1) Mandrel; 2) washer; 3) nut; 4) cover.

In a check made without taking it from the mandrel, the inside-machined cover must lie within the tolerances for radial and end wobble of the lock with respect to the ball-bearing bore; the wobble may not exceed 0.01 mm.

For final outside machining, the cover is set up on a mandrel (Fig. 44) inserted into the taper of the machine spindle, with a radial and end wobble not exceeding 0.02 mm. The cover snaps firmly into the

mandrel groove at its lock (Fig. 42c) and is pressed against the mandrel face by tensioning the nut on the mandrel tailpiece, which passes through the hole in the boss with its flange resting against the boss face. The carriage is set at 80° and locked and the outside surface of the cover is turned through to its final thickness at a 10° angle to the boss if the casting thickness has been found to be greater than specified. The cover flange at the lock is spotfaced, holding the dimension A_1, and the boss diameter d_2 is given its final turning.

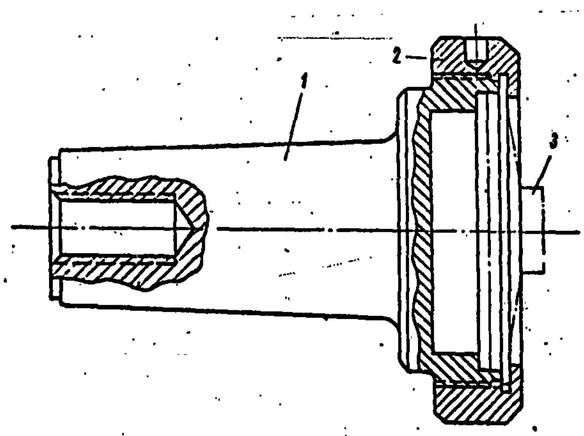


Fig. 45. Mandrel for cutting thread in boss. 1) Mandrel; 2) nut; 3) cover.

The cover is mounted in a mandrel (Fig. 45) for cutting the threads for the ball-bearing nut in the boss. When the mandrel is set up in the machine spindle, a gauge is used to check its wobble (radial and end), which may not be greater than 0.002 mm. The cover is placed with its lock on the bead of the mandrel and tightened against the face with the mandrel nut (Fig. 42d); then the gauge is used to check the radial wobble of the ball-bearing bore, which should not exceed 0.004 mm. When the cover has been placed on the mandrel and secured, the boss is spotfaced, maintaining its height l_1 to the ground surface of the cover lock; the hole is bored in the boss for threading at diameter d'_2 and a groove cut for extracting the threading tool without

disturbing the dimension of the ball-bearing hole.

The same mandrel is employed in thread-cutting, with the permissible radial wobble with respect to the hole bored for the thread set at or less than 0.01 mm when it is set up; the threading operation is performed with a cutter whose radial wobble with respect to the ball-bearing bore may not exceed 0.05 mm. This figure is not verified, but is ensured by the fabrication procedure. Preparation of the thread is a highly critical task. The thread gauge must be screwed tight all the way into the threaded section; the thread may have no stripped turns or pits. The stability of the negative allowance for the ball bearings in the assembled gyromotor depends on the quality of the thread.

After the final lathing operation, holes are jig-drilled in the cover for the bolts that will secure the cover to the housing; also for the bolts to mount the stator, the insulated leadout grommets and other holes. Then the holes are counterbored, chamfers removed, and the holes for the insulation grommets reamed out, holding them to precision class 2; sharp edges and burrs are removed after counterboring, the thread vanish is trued and after all operations have been inspected the covers are sent on to the finishing shop for anticorrosion anodizing.

§31. FABRICATION OF BEARING NUTS

The bearing nuts are made from Type D1T or D16T duralumin; rod stock is first lathe-turned on its outside diameter with a machining allowance; then blanks are cut with a facing allowance. The sequence of subsequent machining is shown in Fig. 46. The blank is clamped in a three-jaw chuck and spotfaced, its outside diameter turned for threading, grooves cut for extraction of the tap (Fig. 46a) and the threads cut. Here the faces are machined to finish class 7, holding the end wobble within 0.004 mm. Then a tapered hole is made for the lubricant

reserve (Fig. 46b) and the cylindrical part is bored out. Holes are then jig-drilled into the completely machined cover for the wrench and setscrews (Fig. 46c).

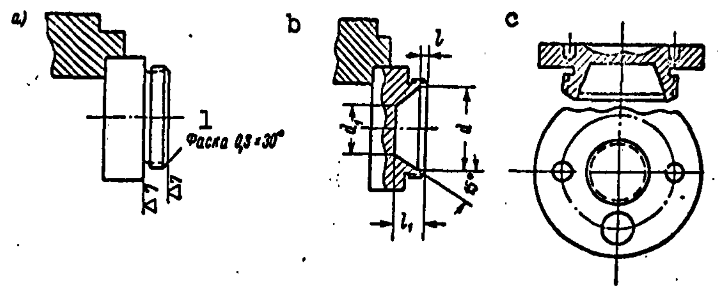


Fig. 46. Procedure for machining bearing nut.
1) Chamfer.

In the manufacture of the bearing nuts, particular attention must be given to securing the tolerance figure for the end wobble of the ground surfaces and maintaining it through subsequent operations, since the nut, whose face bears against the outer ball-bearing race when the gyromotor is assembled, may throw the race off axis if wobble is excessive. Then the balls will not roll exactly along the race on rotation, with the result that the rotor will be unbalanced and the ball bearing will fail prematurely. The stability of the axial tension on the ball bearings depends to a major degree on the quality of the nut thread. The nuts are anodized after machining.

§32. FABRICATION OF ROTOR AND STATOR IRON PACKS

In electric gyromotors, the rotor and stator iron packs are the basic magnetic circuits and are assembled from plates stamped from electrical steel. The following basic requirements are set forth for the iron packs:

1) the magnetic circuits must possess minimal eddy-current and hysteresis losses;

2) they must be simple to manufacture.

Electrical steel according to GOST 802-58 is used as the material for the stator and rotor iron packs: these are dynamo grades E11, E12, and E21 and transformer grades E41 and E42. The specific loss level is higher for the dynamo steel than for the transformer steel.

In spite of this difference between their losses, use of the transformer steel for the magnetic circuits is not always feasible. The primary limitation is the higher-than-usual brittleness of transformer steel with a high silicon content (from 4 to 4.5%). Such high-silicon steels are not adaptable for the production of stamped stator and rotor plates with relatively thin crosspieces. The tabs break off the plates both during stamping and during assembly and machining of the packs, so that rejection ensues. The conditions under which high-silicon steels are stamped are severe; due to their complexity, the dies for the stator and rotor iron are short-lived and wear rapidly.

For series- and mass-produced gyromotors, it is advisable with a view to the requirements of production adaptability to fabricate the magnetic circuits from dynamo steel, and this is the usual practical solution; as regards losses, however, the dynamo steel is considerably inferior to the transformer type. Thus, it is desirable to use a steel for the magnetic circuits of gyromotors that possesses low specific losses on reversal of magnetization on the one hand, particularly at high frequencies, and retains its magnetic and mechanical properties at the level of the dynamo steels on the other. Such a steel type has been developed over the last few years by the [Soviet] industry and given the designation DNP (dynamo steel with low losses). The basic characteristics of DNP steel and certain others are listed in Table 9.

The specific losses of type DNP steel are reduced to the level of the more highly alloyed grades E31 and E41 by special technological procedures. The DNP possesses simultaneously plasticity and magnetiza-

TABLE 9

Magnetic Properties of Electrical Steels

1 Марка стали	2 ГОСТ №	3 P 10/50 *вт/кГ*	4 P 15/50 *вт/кГ*	B_{25}	5 Количество перегибов не менее
6 Э11	802—58	3,30	7,90	15 000	10
Э12		2,80	6,80	14 900	10
Э21		2,50	6,10	14 800	10
7 ДНП	8 Фактические данные	1,60—2,0	3,70—4,20	14 900—15 100	10
Э31		2	4,50	14 600	5
Э41		1,60	3,60	14 500	1
Э42		1,20	2,80	14 400	—
Э43		1,05	2,50	14 300	—

1) Steel type; 2) GOST No.; 3) P, 10/50 w/kg; 4) P, 15/50 w/kg; 5) number of bendings at least; 6) E11; 7) DNP; 8) actual data.

bility at practically the same level as those of the dynamo steels. The use of DNP steel instead of dynamo steel, which possesses high specific losses, and transformer steel with its silicon content of 4-4.5%, which makes the steel brittle, in gyromotors gives rise to no technological difficulties of any sort.

With the object of reducing eddy-current losses on reversal of magnetization and facilitating stamping, plates 0.35 or 0.5 mm thick are used for stamping both the stator and rotor packs. The steel sheets to be used for magnetic-circuit packets in gyromotors must be smooth, without nicks, high spots or traces of corrosion. Dents and projections on individual plates or warping will result in a reduced fill factor when the packets are assembled.

§33. PROCESS FOR FABRICATING IRON PACKS

The production process for fabricating rotor and stator packs for gyromotors should be designed in such a way as to guarantee, beginning with acceptance of the steel and continuing through final assembly of a gyromotor, minimal hysteresis and eddy-current losses and more uniform permeance. The packets must be mechanically joined with good re-

liability and the plates should be tightly applied to one another; failure to observe these conditions will cause the plates to buzz on reversal of the magnetization, so that the gyromotor will produce an irritating noise in operation.

The production process of making the iron packets for gyromotor rotors and stators consists of the following operations: strip cutting, stamping the plates, removing burrs, annealing, insulating the plates, assembling the packets, checking the magnetic properties of the iron, and the finished packets.

Electrical steel is delivered from the mills with certificates indicating the grade of steel and the basic electrical data from tests of this consignment of steel according to GOST 802-58.

Plants that consume steel in large quantities, knowing the type of the steel and its basic parameters (induction and losses), which are listed in the supplier's certificate, sometimes release the steel for production without checking it further. Plants that consume small quantities of steel and receive it in unpacked stacks from various consignments shipped at various times and without certificates must check the basic magnetic parameters of the steel before releasing it for production.

The magnetic characteristics of the steel are determined on the Epshteyn differential apparatus in accordance with GOST recommendations. However, this method requires expenditure of much time in preparing the test specimen and consumes a large amount of material, since the specimen is made from strips that are usually rendered useless as a result. Finally, averaging the measured results is not exactly advisable for verification under industrial conditions, since 3-4 normal sheets are generally used up in the fabrication of a single specimen.

The laboratory for electrical-engineering and magnetic measurements of the AN UkrSSR [Academy of Sciences Ukrainian SSR] Institute of Electrical Engineering has developed a system* by which an apparatus can be built to test whole sheets of electrical steel with the characteristics to be measured read off directly, i.e., without introducing any corrections. Such an apparatus can be used to test 375 × 750 mm electrical-steel specimens, so that the properties of a single sheet of normal dimensions can be determined in the direction of rolling and across this direction and measurements of the following made within a few minutes:

1) the total specific losses in the steel, P_0;

2) the maximum induction B_m;

3) the maximum magnetizing force H_m;

4) the effective magnetizing force H;

5) the loss angle in the steel;

6) on the basis of the measurements listed under 2, 3, and 5, it is possible to compute the values of the complex magnetic permeability, complex reluctance, and their active and reactive components.

Layout of Sheets

Standard electrical-steel sheets have the dimensions 750 × 1500 mm. When the sheet is laid out into separate strips, it is necessary to cut them 1.4 to 1.6 mm wider than the finished plate. The strips are cut out on guillotine or ganged roller-type knives. The precision and output of the guillotine shears are considerably poorer than those of the multiple-roller type, on which the sheet is cut up into the necessary number of strips in a single pass. Figure 47 shows a diagram of the multiple-roller shears. It is necessary to cut all sheets in the same direction, with the roll, in order to reduce warping of the strips, improve stamping conditions, and guarantee a definite orientation of

the plates in the packets (this is particularly important since the permeance is different along and across the roll).

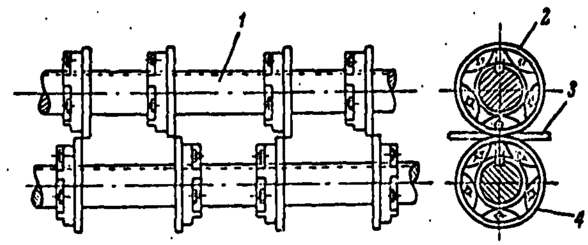


Fig. 47. Diagram of disk shears. 1) Shaft; 2) upper disk blade; 3) material to be cut; 4) lower disk blade.

Stamping the Plates

The plates are stamped on eccentric presses in combined-action dies that provide for punching out of a high-precision plate in a single stroke of the press slide. The plates must have high slot-interval precision, since even a minor error here would result in reduced slot section and make it difficult to lay the windings into the slots. The stamping operation should be performed only with sharp dies so that the burrs formed will not be large. The size of the burrs on the plates also depends on the thickness variation of the material, the gap between the punch and the female die, the precision with which the die is set up, and other factors. The presence of burrs on the plates usually reduces the number of plates in a packet, increases the eddy-current losses due to shorting of the plates by the burrs; burrs formed along the contours of the slots cause damage to the slot insulation when the windings are laid into the slots.

The combined-action stator and rotor dies are complex in design and a high labor cost is involved in fabricating them. Their advantages include high productivity, dimensional precision on the articles stamped, and strict concentricity of their outside and inside contours.

If the dies are made with particular care, dimensions of precision class 2 can be obtained. The male and female parts of the combined-action dies are made from Kh12 or Kh12M steel; if these are not available, use of 5KhVS, KhG, or 9KhVG steel as a substitute is permitted. If the dies are made to quality and used properly, they give 500-800 thousand cutouts with redressing after each 8-10 thousand.

The die designs for stator and rotor plates for gyromotors are similar to those of dies for the stator and rotor plates of miniature electric motors.

A few remarks are in order on operating experience gained with similar dies made from hard alloys, which are capable of making up to 100 million cutouts with an average service life between sharpenings of 2 million, as used at the Mogel'nitsa plant in Czechoslovakia. As compared with alloy-steel dies, the hard-alloy dies – as will be seen from the figures cited above – are distinguished by long service life and punch out plates almost without burrs.

The toughest types of hard alloys are used for making cutout dies; these contain 85% of tungsten carbide and 15% cobalt or 80% tungsten carbide and 20% cobalt. As regards design, these dies differ little from normal dies. In hard-alloy dies, all components subject to wear during operation must have high durability. The clearance between the punch and the female die in these diesets is made somewhat larger than in the case of steel dies; it is adjusted in accordance with the hardness of the material to be stamped between 10 and 14% of its thickness. The blanks for the dieset components – the punch and female part – are made with machining allowances. The allowance varies from 0.3 to 1 mm. Machining to the final dimensions is by the electroerosion process and by grinding with carborundum or carbonado wheels. This plant prepared a compound five-position die for stator and rotor plates of a small

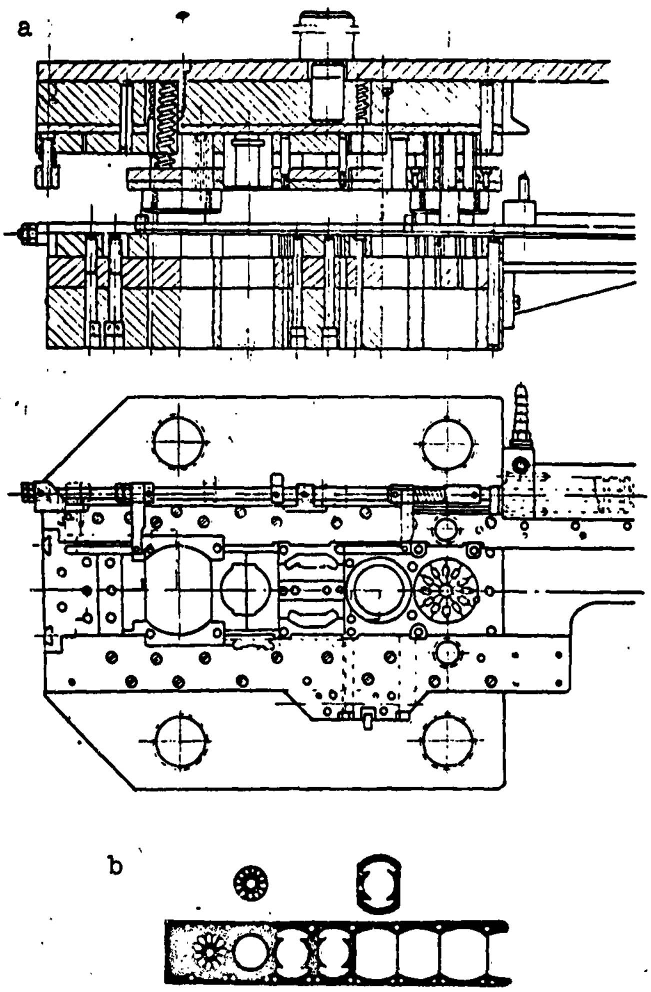


Fig. 48. Diagram of five-station die made with hard alloys (a). Stamping sequence and finished components (b).

slip-ring electric motor; this die is shown in Fig. 48a. Figure 48b shows a stamping produced on this die. The die is designed for operation on an ordinary press, and an automatic pneumatic device should be used on it to feed the strips to be stamped. A feeding device is set up on the die. Two lever arms are used to grip the material; these have fingers on their working ends with cylindrical surfaces and slightly beveled edges. As the material moves forward, the fingers drop into special holes and during the reverse motion they move up

onto the strip. The return motion takes place with the press slide at the top of its stroke. The levers are mounted on shafts connected to the piston rods of pneumatic cylinders. An additional lever with its working end going to the outside of the die is carried on the shaft to raise the strip being fed forward. Before the upper stroke of the press slide begins, a cleat secured to the top of the female part is pressed against the end of the lever arm and turns the shaft in such a way that the fingers on the feed levers are raised up above the strip being stamped. The shaft is pivot-jointed to the piston rod. When the fingers have moved onto the strip, a slidevalve switches the compressed air to execute the return stroke of the piston, and with it the entire feed system. The feeding system operates dependably at 110 strokes per minute, with the result that productivity is high.

Despite a number of difficulties encountered in fabricating hard-alloy dies, the durability figures cited above indicate a great economic gain obtainable by introducing them for stamping the stator and rotor plates of gyromotors and other electrical machines.

Removing Burrs

After the plates of the stator and rotor iron packs have been stamped, the next step is, as a rule, removal of the burrs. There are several known methods for deburring, but the most commonly used process is to take them off on special machines with abrasive wheels. The most successful design for such a machine is generally conceded to be that shown in Fig. 49. The machine consists of an abrasive wheel 3 mounted on a spindle that can be shifted vertically with a lead screw, a base table 4 and an endless belt 2, which feeds the plates 1,

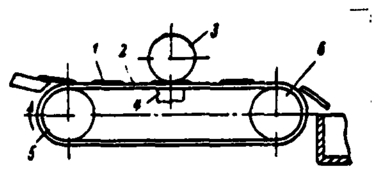


Fig. 49. Diagram of machine for deburring plates. 1) Plate; 2) endless rubber belt; 3) abrasive wheel; 4) stop; 5) driving pulley; 6) tensioning pulley.

which are placed on it with the burrs up, under the grinding wheel. In view of the large quantity of metallic and abrasive dust that is formed, the machines are equipped with exhaust hoods.

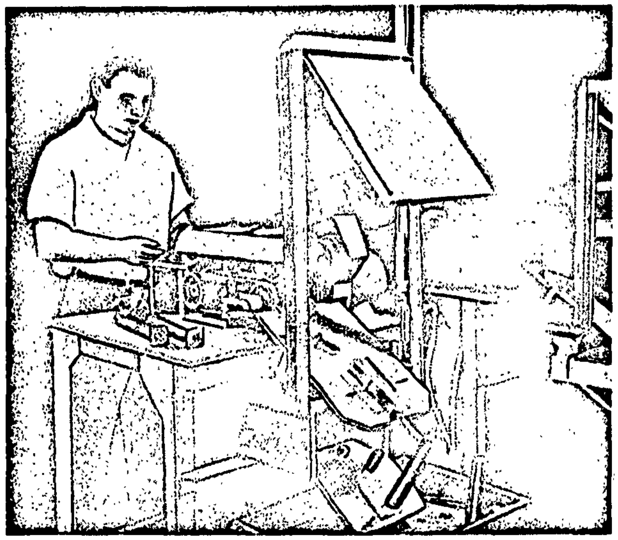


Fig. 50. Machine for removing burrs.

The "Sperry" firm uses special table-top machines (Fig. 50) to remove burrs. The machine consists of two driving spindles run off the same electric motor. Driving sheaves are seated on these spindles. Idler sheaves of the same diameter are set up a certain distance away. An endless belt coated with an abrasive layer is placed over the upper sheaves. An endless leather belt is placed over the lower sheaves. During operation, the sheaves rotate in opposite senses, moving the belts in different directions. Thus, for example, the abrasive belt moves toward the operator and the leather belt below away from him. The plates are laid on the lower belt; when they pass between the belts the burrs are removed from them. Then the plates move along an inclined table for stacking on rods. The operator can monitor stacking of the iron on the rods in a mirror set up at an angle to the table. A typical procedure, once the plates have been pushed onto rods after

stamping, is to transport them in this form to all other operations right up to the actual assembly.

Annealing the Plates

When the strips are cut on the shears and stamped, internal stresses (strain-hardening) arise along their perimeters and throughout the entire mass of the metal, so that the magnetic properties deteriorate and the hysteresis losses increase. Strain-hardening, with the sharp drop in the magnetic properties and the increase in hysteresis losses propagate along the perimeter of the stamping to a distance of 0.5 to 1 mm. Strain-hardening and internal stresses in the metal are usually relieved by annealing.

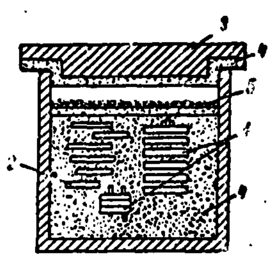


Fig. 51. Box for annealing plates. 1) Plates in packets; 2) individual plates; 3) cover; 4) asbestos; 5) iron filings.

Electric furnaces are used to anneal the stator and rotor blades for gyromotors. The rotor plates are annealed after varnishing, which ensures that the varnish coating will not be burned out when the shunt winding is cast in. Rotor plates are annealed in iron boxes at temperatures from 500 to 550° for 1-1.5 hours with access of air permitted. Although it does not guarantee full restoration of the magnetic properties of the plates in the strain-hardened perimeter area, such annealing takes place at a temperature at which the volatile substances in the insulating varnish are completely burned out. A consequence of their retention is formation of gas blowholes in the winding when the shunt winding is poured in, due to evaporation of the volatile substances; this constitutes cause for rejecting gyromotor rotors. The film on the annealed plates should be lustrous, even and dark brown in color and should not scale off when the plate is bent double. Stator plates that have been matched and bundled

are annealed in closed iron boxes (Fig. 51). A bed of asbestos is poured in over the bundles, followed by blanketing with gray iron chips. The boxes, which are lined with refractory clay, are loaded into the furnace at a temperature of 350-400°. The furnace temperature is raised to 850° and the boxes held at this temperature for three hours. The boxes are cooled together with the furnace down to 200° and thereafter in air.

Such annealing, without access of air, produces plates with good magnetic properties and only very minor scaling.

Insulation of Plates

As we noted above, the plates are coated with an insulating varnish -- after annealing for the stator plates and before annealing for the rotor plates -- that forms a surface film with good insulating properties. Prior to varnishing, the surfaces of the plates must be clean, have no grease spots or traces of corrosion to which the varnish might take poorly. For this purpose, the plates are degreased before annealing by washing in gasoline or by some other method that ensures the appropriate cleanliness.

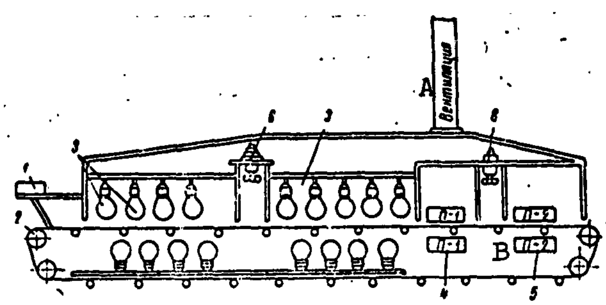


Fig. 52. Setup for varnishing plates.
A) Ventilation; B) P-2.

The stator and rotor plates are coated with Bakelite lacquer or Glyphthal-oil paint No. 1154 using special apparatus (Fig. 52). This installation consists of the varnishing machine 1, the apron conveyor

2, two chambers with infrared lamp 3, two chambers with electric heating devices 4 and 5 and two electric fans 6.

The varnishing machine (Fig. 53) has four rollers that are driven through a gear transmission from an electric motor. The two lower steel rollers 1 are partly submerged in the Bakelite lacquer and, when turned, feed it onto the upper rubber-coated roller 2. Bakelite lacquer with a viscosity rating of 25-30 sec through the NIILK No. 7 funnel, flows by gravity into the housing 3 of the unit from the supply tank 4. The plates to be varnished are dropped into the slot in the housing cover, pass between the rotating rubber-coated rollers, and descend on an inclined chute onto a metallic slat conveyor.

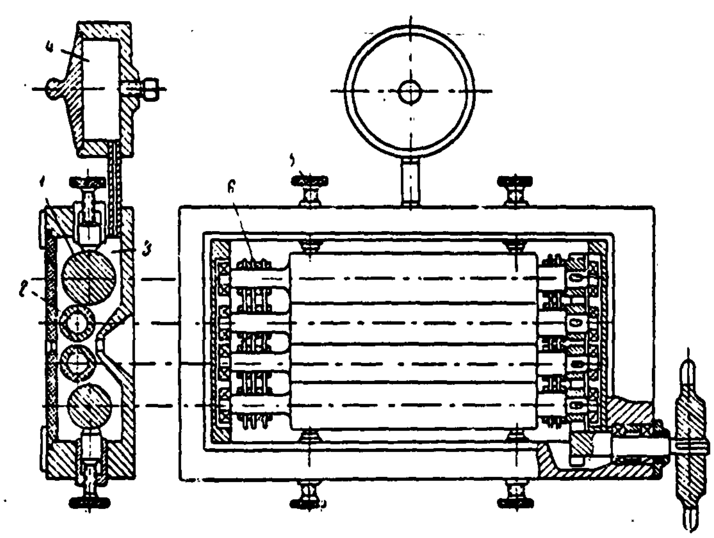


Fig. 53. Varnishing machine. 1) Steel rollers; 2) rubber-coated rollers; 3) housing; 4) tank; 5) adjusting screws; 6) gears.

The thickness of the coating applied is controlled by the gap between the rubber-coated rollers by manipulating the adjusting screws 5, and it varies on the average from 0.01 to 0.015 mm.

The conveyor belt moves the plates into the first chamber with the 500-watt infrared lamps, which are mounted above and below the

belt. Intensive evaporation of the solvent from the varnish coating takes place here at a temperature of 100 to 110°.

The process of driving the solvent out of the coat continues in a second infrared chamber under the same drying conditions as in the first chamber. Then the plates move on into the first chamber with electric heaters 4 (Fig. 52), where the temperature reaches 400 to 450°. Here the varnish coat is brought to stage B, i.e., it loses its ability to dissolve in organic solvents.

In the second electrically heated chamber 5, the temperature is 650 to 700°. In this chamber, the varnish coat acquires the properties corresponding to stage C, i.e., it is fully polymerized. It turns brown in color. The coated plates from the conveyor are collected in iron boxes.

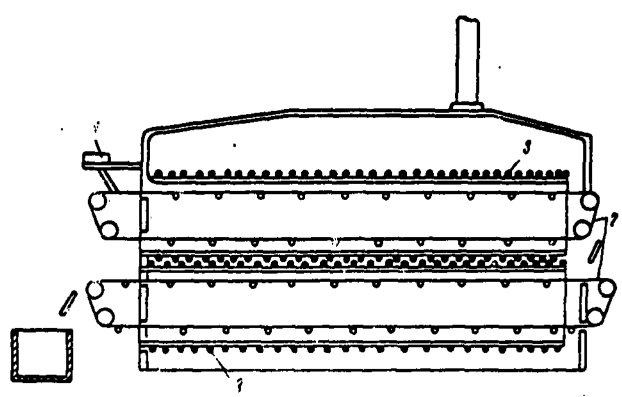


Fig. 54. Machine for varnishing plates with induction heating. 1) Varnishing machine; 2) conveyor; 3) steel boxes with windings.

Units in which heating and finishing of the varnish coat on the plates are carried out by the induction method have recently come into widespread use. A diagram of such a unit is given in Fig. 54.

Like the one described above, the unit consists of a varnishing apparatus of the same design and two apron conveyors that move in oppo-

site directions. The upper slats of the conveyors run in metallic boxes welded up from sheet steel. On top, the boxes are insulated with sheet asbestos on which insulated copper wire is wound directly. The plates are heated on the conveyor because the alternating current flowing in the winding on the metallic boxes sets up a magnetic field that changes polarity with the frequency of the supply voltage. The usual frequency is 50 cycles. Large eddy-current and hysteresis losses take place during reversal of magnetic polarity, and these result in heating of the entire metallic conveyor system, including the plates that the conveyor is carrying. Plates that have passed the entire length of the upper conveyor are fed to the lower one and move back in the opposite direction with heating continued. As the varnished plate passes along the upper and lower parts of the conveyor, the Bakelite varnish first loses its volatile solvent and then passes successively through all stages to complete polymerization. This apparatus is more economical because the heat present in the boxes is dissipated slowly and the heating element is made from copper wire and is not heated above the temperature of the outer surface of the box. The temperature inside the box does not rise above 250°.

Plates that have been varnished with these units give a fill factor of 0.93-0.96. The resulting varnish film is elastic, nonhygroscopic, possesses adequate mechanical strength, adequate insulating properties and protects the plates from corrosion.

Live-Steam Oxiding of Plates

In many cases, plates for the stator and rotor packets are vacuum-impregnated with insulating varnishes after winding. Penetrating between the plates, the insulating varnish provides additional insulation. To reduce the labor cost and economize on insulating lacquers, the plates are subjected to live-steam oxiding.

With electrical-steel plates heated in a container in an atmosphere of mixed steam and air at a temperature of 500 to 550°, live-steam oxiding forms an oxide coating on the plate surfaces that guarantees anticorrosion and insulation protection of the plates during operation in the assembled packets.

Plates subjected to live-steam oxiding must be clean, have no burrs, have been chemically degreased, and have no scale or signs of corrosion on their surfaces. In the presence of scale and corrosion on more than 5% of the total plate surface area, the plates are pickled in sulfuric or hydrochloric acid with inhibitors or in phosphoric acid with subsequent neutralizing and drying.

Live-steam oxiding of the plates is carried out in a special apparatus (Fig. 55) by the following procedure. The prepared plates are assembled into small bundles, tied up with steel wire and placed in a special container 1 made from stainless steel for installation into the heat-treating furnace. After the container has been loaded, it is sealed tightly with a bolted-on cover. A thermocouple is inserted into a hole in the flap of cover 2 and the furnace and recording instruments switched on. After the furnace with the container and plates has been heated to a temperature of 500 to 550°, the plates are held at this temperature for one hour. Plates of E42 transformer steel are held for 2 hours at a temperature of 750 ± 30° and then cooled to a temperature of 550° before admission of the steam into the container.

The steam pressure in the steam line 3 is raised to 3-5 atm, the valve 4 is closed, and the steam is at first blown out at the outlet by opening the valve 5. Then valves 8 and 5 are closed and the steam is blown through the trap 6 by opening valves 7 and 4 for this purpose. After valve 7 has been closed, the steam is blown through the duct by opening valves 8 and 9; then valve 9 is closed and valves 10 and 11

opened, thus admitting steam into the container and oxiding the plates. The steam is fed into the container under a pressure of 3-5 atm for 2.5 hours for dynamo steel and 3-3.5 hours for transformer steel; it is necessary to watch the outlet of steam from the steam line in order to avoid sticking of the valve and condensation of the steam. The steam pressure at the outlet should be lower than 0.2-0.3 atm. The temperature of the furnace with the container must be maintained at all times between 500 and 550°.

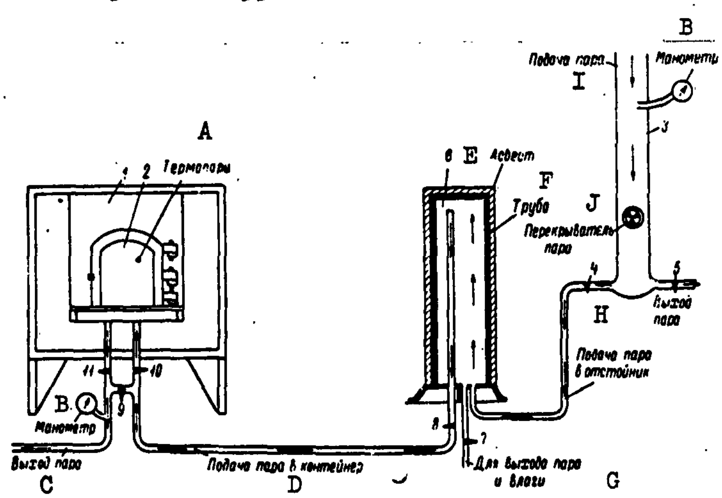


Fig. 55. Diagram of live-steam apparatus. A) Thermocouple; B) pressure gauge; C) steam outlet; D) feed of steam into container; E) asbestos; F) tube; G) for release of steam and moisture; H) steam feed into trap; I) steam feed; J) main steam valve.

When the time necessary for oxiding has elapsed, valves 4, 8, 10, and 11 are closed, the furnace heat is switched off, and it is allowed to cool together with the container to a temperature of 200°. Then the thermocouple is pulled out, the registering instruments are shut off, the furnace door and the container cover are opened and the bundles removed from the container and stacked up on skids, on which they ride to final inspection, followed by assembly of the stator and rotor packs. The temperatures of heating and cooling are monitored from the

traces of the automatic recording instruments. The oxide coating should be a dense continuous layer, dark blue in color, over the entire surface of the plate. Uncoated spots, pores and cracks on the plates are not tolerated; such defects are checked for by dipping plates taken at random in a freshly prepared 3% solution of copper vitriol for 30 sec. If there are more than three red copper dots on 1 cm^2 of plate surface, another inspection is carried out with twice the number of plates. The oxide coating must have an insulation resistance no lower than 5 ohms when checked with a 7-mm^2-area electrode on various plates and must not exfoliate when the plates are bent 90° around a mandrel 20 mm in diameter.

If the specifications as to the quality of the oxide coating are not satisfied in repeated tests on the plates, the plates of this consignment are rejected and returned to be live-steam oxided all over again.

<u>Assembly of Packets</u>

The rotor packets are assembled with the required number of plates taken from among the plates that have been annealed after varnishing or oxiding, are tied up with wire, and delivered in this form for casting of the shunt winding. Prior to casting, the plates are piled up in special assembly holders with locators through the slots, pressed to the required thickness with a specified tolerance and placed in a centrifugal-casting mold as described in Chapter 2.

The "Sperry" firm uses special mandrels (Fig. 56) to assemble rotor packs with oblique slots. Working according to sizes, the operator matches the required number of plates to the smooth mandrel and pulls them toward himself, moving them off the smooth mandrel onto a helical-fluted one. The helical mandrel has a smooth shank that push-fits into a hole in the smooth mandrel, on which the prepared plates are orig-

Fig. 56. Assembly of rotor packs with oblique slots for casting.

inally situated. As the required number of gauge-separated plates moves from the smooth mandrel to the helical, they acquire the necessary skew along the specified spiral as their slots follow the fluting of the helical mandrel, the thickness of which corresponds to the cut-out in the plates. With the packet assembled on it in this manner, the helical mandrel is taken out of the hole in the smooth mandrel; a hydraulic press is used to reduce the packet to the required size. Then the helical mandrel is pushed out of the iron pack and a cylindrical mandrel pressed into the bore to hold them when the winding is poured in. After rough machining of the shunt winding, the mandrel is taken out of the pack.

After varnish insulation or oxiding, the stator plates are assembled into packs by count or weight and tied up with wire. Gyromotor stator packs are usually assembled on a special bushing that is secured in the cover or pressed on over the cover bushing as shown in Chapter 1. For assembly of the stator pack, the bushing is set up in a fixture and smeared with Bakelite lacquer; the end plate is pulled on over it and then the entire pack is pressed on by applying pressure to the top

plate. The end plates are taken from 0.8 to 1 mm thick, depending on the diameter and thickness of the pack. After pressing onto the bushing, the pack is compressed on a hydraulic press, using the required pressure to bring it to size; without relieving the pressure, the bushing is flared to secure the pack.

§34. MACHINING OF PACKS

The stator packs (Fig. 57) that have been assembled and secured to the bushing by flaring the ends go on to machining, which consists of the following operations. The pack is mounted on a lathe in a bored-out pot chuck by its outer surface and given its final turning, followed by reaming of the hole in the bushing. Then, using the bushing bore as a base, the seating end of the bushing is spotfaced and its outer diameter turned to fit the seating bore in the cover. Then, using the bushing bore as a base, a cylindrical grinder is used for final infeed grinding of the pack's outer surface. Formulas that guarantee machining without forcing in any burrs on the plates are used in the grinding operation; this protects the plates from electrical contact.

After grinding, the stator packs are dried and sent to the winding shop for placement of the winding into the slots (see Chapter 4).

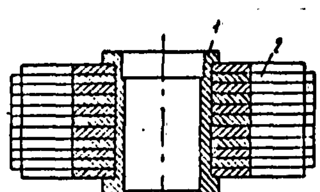


Fig. 57. Stator pack. 1) Bushing; 2) stator plates.

After the shunt winding has been poured in the slots, the rotor packs are sent for machining. First the pack is secured by its outer surface in a pot chuck and the hole first rough-bored and then rebored with an allowance for final boring on the completely finished rotor. One of the winding faces is spotfaced, holding to the specified dimension of the winding-ring thickness, and given the final turning operation on its outside diameter. The pack is set up on an expansion

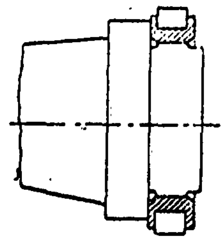


Fig. 58. Mandrel for machining rotor shunt winding.

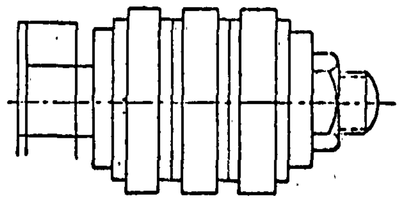


Fig. 59. Mandrel for grinding rotor packs on outside diameters.

mandrel (Fig. 58) by the bore diameter, the other end is spotfaced and the second shunt-wound ring given its final turning to ensure an end wobble no greater than 0.05 mm and a class 5 surface roughness.

Prior to grinding of the outer surface of the packs, they are traverse-turned on a lathe; several packs are set up on a single mandrel for this operation (Fig. 59). Using the same mandrel, a cylindrical grinder performs the final operation on the outside surfaces of the packs to provide for fitting into the rotor flywheel by a force fit of precision class 2 and a class 7 surface roughness without producing burrs on the plates.

After grinding, the packs are washed and dried in a thermostat and provided with the gyromotor serial number; the quality of the winding is verified on a machine by the method described in Chapter 7, and preservatives are applied by the technological process described in Chapter 4.

Manuscript Page No.	[Footnotes]
80	The points specifying surface-finish and surface-roughness classes poorer than class 1 of GOST 2789-59 went into effect as of 1 October 1959.
133	For greater detail see V.F. Petrochenko, BTI [Bureau of Technical Information], 1957, No. 4.

Manu-script Page No.	[List of Transliterated Symbols]
68	т.шт. = t.sht. = [unidentified], shtuka = [unidentified], unit
68	т.п.з. = t.p.z. = [unidentified]
73	ОСТ = OST = Obshchesoyuznyy standart = All-Union Standard
78	мин = min = minimal'nyy = minimum
79	ГОСТ = GOST = Gosudarstvennyy obshchesoyuznyy standart = = All-Union State Standard
79	а = a = arifmeticheskiy = arithmetical
79	ск = sk = srednekvadratichnyy = root-mean-square
79	ср = sr = sredniy = average
102	макс = maks = maksimal'nyy = maximum
121	ЦИАТИМ = TsIATIM = Tsentral'nyy nauchno-issledovatel'skiy institut aviatsionnykh topliv i masel = Central Scientific Research Institute for Aviation Fuels and Oils
133	м = m = maksimal'nyy = maximum
141	НИИЛК = NIILK = Nauchno-issledovatel'skiy institut lakokrasochnoy promyshlennosti = Scientific Research Institute of the Paint and Varnish Industry

Chapter 4

WINDING AND ANTICORROSIVE COATING

§35. GENERAL REMARKS

The majority of electrical gyromotors performing in instruments are supplied from converters giving three-phase alternating current of high frequency. As was shown above, gyroscope instruments and therefore also gyromotors which are the essential elements of these instruments are designed to operate under conditions that depend on the mechanical and climatic influences. Therefore, stringent requirements are imposed on electrical gyromotors when their stator windings are tested, even though the supply voltage may be low. During the operation the stator windings must not have any short-circuited turns; their insulation resistance relative to the body must not drop below 2 megohms during operation in an atmosphere of 95 + 3% humidity. The winding must not run hot. The temperature of the stator winding of the gyromotor, under tough operating conditions, is not allowed to reach more than 80°C; there must not be any traces of the impregnating varnish running off nor of other faults putting the gyromotor out of service.

The reliable service of gyromotors, which is determined by the electrical parameters, depends exclusively on the quality of the material used, the accuracy of assembly, and the technical discipline.

The technical process of winding in the manufacture of a gyromotor involves the following operations: insulation of the stator iron pack, laying of the winding wire in the slots, impregnation, mounting

of the winding, and also testing of the quality of the stator winding.

§36. MATERIALS FOR GYROMOTOR WINDINGS

For stator windings in gyromotors, wires of various diameters are used, made from electrolytically tempered red copper.

Before wires with Viniflex and Metalvin insulation were manufactured by the consumer goods industry, enameled PEL wire (State Standard 2773-51) and in some gyromotors PELShO wire (with a silk insulation) were used for the stator windings. At present, stator windings are made of PEV-2 wire (State Standard 6324-52) and of wire with an increased heat resistance, coated with an organosilicon varnish and ensuring service over a temperature range of -60 to +200°C.

For soldered wire junctions, and for soldering ends and terminals, a soft solder is used which consists of tin and lead and a certain quantity of antimony. The higher the tin content in the solder the better it flows and the easier it runs into the gaps between the faces to be soldered. POS-61 and POS-40 are usually employed in the manufacture of gyromotors. An acid-free flux consisting of a 30% solution of rosin in alcohol is used for soldering.

To ensure the reliable operation of the gyromotors at reduced humidity and over a wide temperature range, as required by the technical specifications, A-class materials, in accordance with State Standard 183-55, with a limiting temperature of 105°C are used for the insulation of the stator windings.

The slot insulation, the outer insulating plates of the stator packs, and the insulation of the sleeves for the face parts of the windings are made of electrically insulating cardboard of the following types:

EV – electrokarton, air, cellulose, made of wood cellulose; chiefly used for the outer plates and insulation of the bushings for

the front parts of the windings;

EVP – electrokarton, air, cellulose, pressed. Made of wood cellulose or cotton fiber, impregnated. Used for insulation of the slots;

EVT – electrokarton, air, rag, made of a waste-cloth base. Used as a wear-resistant packing for recess insulation in stators with close packing of the wire in the recesses, and when the front parts of the windings are subject to pressure.

The varnished fabrics consist of cloth impregnated with varnish which forms an elastic film of high insulating quality. In the manufacture of gyromotors only clear, yellowish brown varnished fabric is used; it is elastic and resistant to water, gasoline, and mineral oils. The types used are LSh-1, LSh-2, and LShS. Black varnish fabric is not used since it is less resistant to gasoline and mineral oils. LSh-1 varnished fabric is silk, clear, used for additional slot insulation. LSh-2 varnished fabric is silk, clear, used as a substitute for LSh-1. LShS-1 and LShS-2 are special silk varnished fabrics, clear, used as a substitute for LSh-1 or when higher electrical strength is required.

Recently, new insulating materials have been used for recess insulation in electric machines; they can also be used in the manufacture of gyromotors, as for instance:

Film of Lavlas resin which has a high mechanical and electrical strength even when it is very thin; this reduces the packing factor of the slot.

Fluoroethylene-4 (VTU M-549-54) – whitish gray, slightly transparent as a thin film, feels like paraffin. It has exceptionally high dielectric properties. It is characteristic that these properties vary but slightly in the large temperature range between -60 and +250°C. The plastic is resistant to various strong acids and alkalis and dis-

solves in none of the known solvents. Fluoroethylene-4 can be used for the electrical insulation of the stator recesses. Insulations made of this material do not become wet and do not swell in water. This makes it possible to use them in high humidity. Fluoroethylene-4 is distinguished by its high strength.

Stekloeksapon LSE-19. For normal heat-resistant insulations, the silk and cotton varnished fabrics can be replaced by a Stekloeksapon varnished fabric; as compared with the former, the latter has a greater dielectric strength, resistance to moisture and heat, and is less expensive.

Getinaks (State Standard 2718-54). This consists of paper impregnated with synthetic, heat-resistant, bakelite-type resins pressed in several layers (depending on the required thickness) under high pressure, definite temperature and holding time. Various types are available in the form of sheets of various thickness. In gyromotors they are used for recess cladding. The most suitable Getinaks types for this purpose are the types V and B which are easy to die-stamp both hot and cold.

Polyvinyl chloride tubes made of polyvinyl chloride resins with and without dye pigment. They are used as an additional insulation on the gyroscope stator wire ends. The tubes employed are colorless.

Fibers made of silk, since only these are not hygroscopic, are used to protect the ends of the winding wires at the terminals.

Winding wires used are PEV-2 wire, enameled with Viniflex, bifilar, and PEV-3 wire, enameled with Viniflex, trifilar.

In gyromotors operating at increased temperatures, besides these wires, organosilicon-insulated PETK4 wire (TUO MS 505.037-56) is employed.

The ends leading out of the stator windings are MGShDO or MGShDOK

wires insulated with silk or caprone:

MGShDO wire is a multiple, flexible conductor with a double cover and braiding of natural silk;

MGShDOK is a multiple, flexible wire with a double cover and braiding of caprone;

MGV is a flexible, multiple-stranded cable covered with a polyvinyl chloride coating.

§37. INSULATION OF THE STATOR PACKS

After mechanical working and drying, the stator packs are sent to be insulated. Before insulation, all the recesses are cleaned from dust and projecting edges. The pack is insulated as follows: 1) the outer insulating plates, which are made of electrocarton and have the shape of the stator plates with their outer diameter reduced by 1-1.5 mm, are glued to the outer plates of the pack with BF-4 adhesive; 2) the ends of the bushings for the front parts of the windings are insulated by wrapping a special, insulating cardboard or varnished fabric packing round it and gluing these together; 3) the recess insulation is applied.

Before the winding is packed into the recesses of the stator pack the recess insulation is installed which consists either of cardboard alone or of cardboard with varnished fabric, or of other insulating materials (fluoroethylene, Lavlas film).

The recess is insulated partly by hand as the winding wire is laid into the recess. In this case, the recess insulation is trimmed on a small cutting machine somewhat longer than the pack (1-1.5 mm) and to such a width that it protrudes 5-8 mm above the pack when the recess is lined. The productive capacity of recess insulation mounting by hand is not high.

In stator packs with external straight recesses the so-called

continuous recess insulation is partly used; it is applied either by hand or on special automatic machines. In continuous recess insulation, a band previously trimmed to 1-1.5 mm longer than the pack is pressed into the recess by a plane punch and is then shaped to the slot contours by means of punches with cross sections matched to the cross section of the recess with the insulation. The two ends of the band are then glued together. Such a continuous recess insulation is suitable for machine winding since the directing jaws can be applied more easily to the pack, and since it will not interfere with the rotation of the pack. Moreover, the wire cannot fall between the insulation and recess wall when it is wound on. The insulation lies on teeth and is cut off after the entire winding has been fitted; protruding parts are bent into the recesses.

The mechanization of continuous insulation fitting and of the machine winding can easily be carried out in the production of stator packs with straight external recesses; this is difficult in the manufacture of stators with slanting recesses.

Figure 60 shows the kinematic scheme of one of the machines for continuous recess insulation in gyromotor stators.

The machine can be used for mounting the continuous insulation in the recesses of stators with various numbers of recesses, various pack lengths, and recesses of various profiles. The mounting of the stator with a mandrel placed in the opening of the bush in the center of the machine, the loading of the insulating film into the reel, and the removal of the stator is performed by hand. The insulating film is applied automatically, and the machine is shut down automatically too.

The machine is set in motion by an electromotor with a V-belt transmission to a reducing gear on a camshaft 1. Seven cams on the latter move the follow-up mechanism by means of transmission mechan-

isms. Through the hinged transmission 49 the cam 8 transfers the motion to the part 31, which presses the insulating film 33 to the stator as it moves forward and then moves back to its initial position under the action of the spring 32. Through the hinged transmission 50, the cam 7 drives the part 35 which carries a flat punch 30. The latter presses the film into the stator recess so that the film forms a

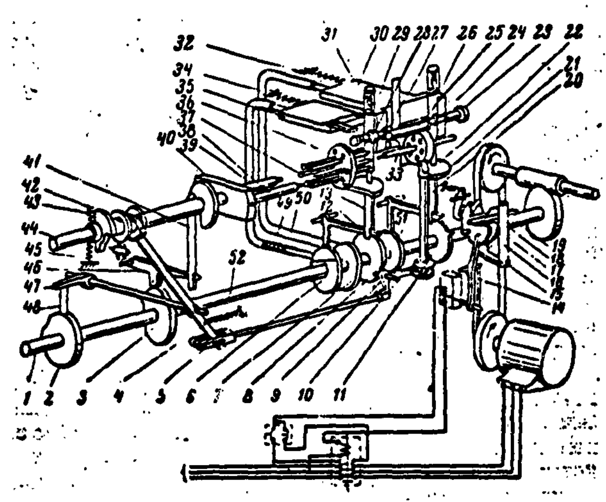


Fig. 60. Kinematic layout of the machine for mounting the recess insulation in a stator with straight recesses.

loop in the recess. After this the part 35 returns to its initial position under the action of the spring 34. Through the push rod 48 and the levers 47 and 4, both mounted on one axle, the cam 2 causes the forward motion of the connection 42 and therefore also of the rod 44 to which 42 is connected. At the end of the motion of the rod 44, the second arm of the lever 4 acts through the pull rod 5 to turn the lever 9, which is connected to the fixing pin 10. The latter moves down and unlocks the stator before its rotation. The rod 44 carries a face plate 40 with two push rods 38 and 39; when these are displaced their pins enter two diagonally opposite holes in the disk 36.

When the push rod 39 is shifted it catches the punch 37, inserts

windings by a varnish insulation covering in one piece the entire outer surface of the iron pack, the end plates of the pack, the surface of the drum, and the inner surface of the recesses. It was necessary to choose the varnish such that a film of it would adhere firmly to the iron surface, yield a thin layer and form no pores (due to evaporation of the solvent) when drying, and have good insulating properties. After numerous experiments a decision was made in favor of an epoxide resin layer.

The epoxide layer proved its ability to solidify without any volatile substances separating out; in most cases it is these that are responsible for the formation of pores and blisters and that do not allow a uniform material to be obtained. The shrinkage exhibited by epoxide resin layers is only slight and they adhere to metal surfaces. The insulating properties of the epoxide layers proved to be entirely sufficient.

Under standard conditions, the usual epoxide resins are either highly viscous liquids or solid substances that are thermoplastic without a hardening agent. When mixed with a hardening agent, the epoxide resins will solidify on heating or cooling, i.e., they will go over into a solid, infusible and insoluble state. The properties of solidified epoxide resins are determined to a considerable extent by the hardening agents. The most complex technical problem which has not yet been solved consists in working out an engineering process for applying a thin uniform layer inside the half-closed recesses.

After the insulation has been applied and tested for its reliability, the stator packs move on for winding. Three forms of gyromotor stator winding can be distinguished: spool, hand, and machine winding.

§38. TEMPLATE WINDING OF STATORS

When stators are spool wound, the sections of the wire are wound

upon special spools on ordinary winding machines. One of these spools is shown in Fig. 63.

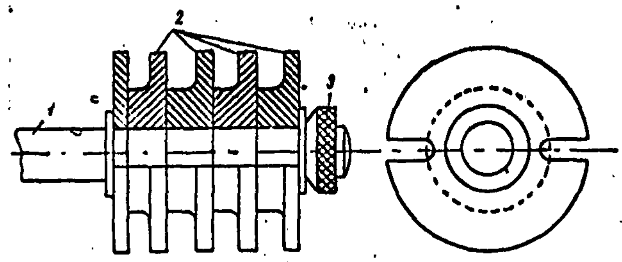


Fig. 63. Spool for winding sections of stator winding. 1) Chuck; 2) spool; 3) nut.

The spools are cylindrical and have the same number of recesses as there are sections in the phase. In this way the sections can be wound continuously on the entire phase. After winding, the sections are connected by wires through special slots in the spool that are on opposite sides of it. The sections can be wound separately too. After the sections have been removed from the spool the number of turns on them is verified on a device which indicates the number to within one turn. The scheme of such a device is shown in Fig. 64a. The device consists of a cylindrical iron core slotted in two places and made of laminated dynamo or transformer steel; the plates of the core are cemented together. The slit is necessary to make it possible to exchange the tested sections; it has to be finished carefully to ensure a minimum gap width. The rubber padding 8 acts like a loop which makes it possible to open the magnetic circuit of the transformer. The primary winding 2 should also fasten the rubber padding to the iron core. The insulated nonmagnetic support 3 serves as a base on which the device is mounted. The insulating textolite spacer 4 is the base for the standard section 5 and test section 6.

The standard and the test section must have the same shape and

must be as close as possible together, symmetrically disposed about the gap of the core.

A schematic diagram of the device is shown in Fig. 64b. The device is a transformer with the primary winding 1, the so-called feed

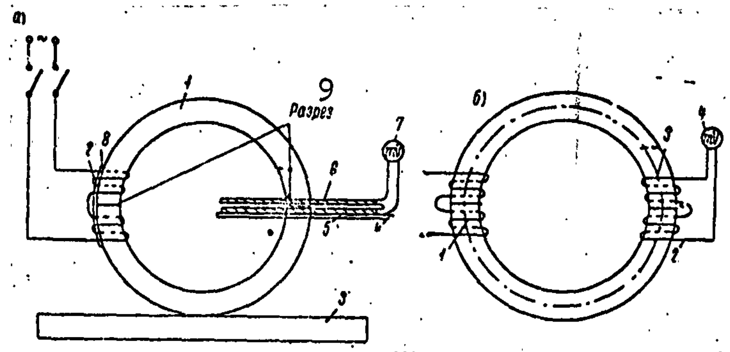


Fig. 64. Device for examining the number of turns on the sections (a). Schematic diagram (b). 1) Iron core; 2) feed winding; 3) insulating base; 4) textolite lining; 5) standard section; 6) test section; 7) millivoltmeter; 8) rubber padding; 9) gap.

winding which is fed by alternating current of high frequency (1000-500 cps) producing a variable magnetic flux in the magnetic circuit. The flux intersects the contours of the standard and test sections, 2 and 3, and induces equal electromotive forces in them when they both have the same number of turns. As the sections are connected so that

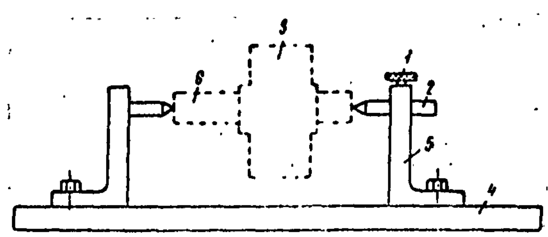


Fig. 65. Vise for stator winding. 1) Screw; 2) movable center; 3) stator stack; 4) base of vise; 5) movable jaw; 6) mandrel.

the emf's induced in them are opposed, the millivoltmeter 4 inserted

in their circuit will show a zero deflection.

When the number of turns on the standard and test sections are not equal, the millivoltmeter will indicate the difference in the emf's induced in the two sections. The greater the difference in the

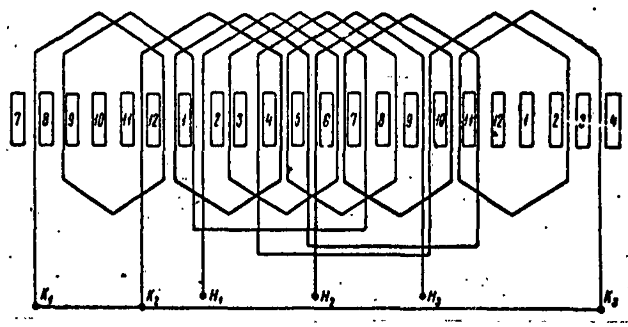


Fig. 66. Diagram of form winding.

number of turns the greater the voltage indicated by the millivoltmeter. The millivoltmeter used is a magnetoelectric instrument with a cuprox rectifier.

After the number of turns has been examined, the ohmic resistance of the section is measured with a bridge. The phases for each stator are matched up according to their resistance so that the difference between their ohmic resistances is not greater than permissible.

The stator prepared as described above is pushed with the opening of its sleeve onto a mandrel with centering holes, and clamped in this manner between centers in a stand (Fig. 65). When the slots are insulated on a machine, the sections are lined beginning with the first recess (any of the stator recesses can be taken as the first). When the recesses are insulated by hand a prefabricated insulation is first inserted into the recess, and then follows one side of the section.

In the winding steps 1-5 on a 12-recess stator (Fig. 66), the sections are mounted in the recesses as follows: first one side of the first coil of the first phase is laid to the bottom of the first re-

cess. One of the sides of the second coil of the first phase is laid to the bottom of the second recess. The input end of the first phase is led out of the second recess; for this purpose the output end is soldered to the beginning of the winding of the section. The soldered junction is carefully insulated with varnished fabric and is embedded in the front part of the winding. Then, the sides of the 1st and 2nd coils of the third phase are inserted to the bottom of the recesses 3 and 4, respectively. The output end serving as the end of the third phase is led out from the fourth recess. Further, the sides 1 and 2 of the coils of the second phase are inserted into the recesses 5 and 6. The output end of the beginning of the second phase is led out of the 6th recess. Above, on the lower sides of the coils of the 2nd phase, the second side of the first coil of the first phase is inserted in the recess 5, and, correspondingly, the upper side 2 of the coil of the first phase in the sixth recess. The projecting part of the recess insulation is clipped and fitted properly into the recesses. Getinaks wedges are embedded in the latter. In this way the recesses 5 and 6 are filled up. Further, the lower sides 3 and 4 of the coils of the first phase are inserted into the recesses 7 and 8. From the eighth recess the output end is led out to serve as the end of the first phase. In the upper part of the recesses 7 and 8, the second sides 1 and 2 of the coils are inserted. These lead out of the 3rd and 4th recesses, respectively. The insulation is clipped and fitted into the recess in which the wedges are fitted above the insulation. In this way the 7th and 8th recesses are filled up. Further, the lower sides of the 3rd and 4th coils of the 3rd phase are put into the bottom of the recesses 9 and 10. The output end serving as the end of the 3rd phase is led out from the 10th recess. The second sides of the 1st and 2nd coils of the 2nd phase, which lead out from the recesses 5 and

6, are inserted on top in the recesses 9 and 10.

The insulation is clipped as before and fitted into the recesses into which the wedges are fitted. The sides 3 and 4 of the coils of the 2nd phase are inserted underneath, the second sides 3 and 4 of the coils of the 1st phase are inserted on top in the recesses 11 and 12. The insulation is clipped and the wedges are put into the recesses 11 and 12. The second sides 3 and 4 of the coils of the 3rd phase are inserted into the recesses 1 and 2, and the second sides 3 and 4 of the coils of the 2nd phase into recesses 3 and 4. At these recesses the insulation is clipped, fitted into the recess, and the wedges are inserted. The ends leading out of the recesses 4, 8, and 12 are star-linked and soldered together. The soldered junction is carefully insulated and put into the front part of the winding. When the sections are mounted in the recess they have to be turned so that the current flows in such a direction as to produce different polarities. The packing process in spool winding is considerably easier when the sections wound are not four-coil but only two-coil. In this case, however, the stack becomes larger.

§39. HAND WINDING OF STATORS

Hand winding of stators for gyromotors is difficult work requiring great care by the workers, in particular when a great number of turns of thin wire are to be wound since these have to be counted when they are fitted into the recess. Despite several shortcomings, hand winding of gyromotor stators is quite widespread.

In hand winding, the stator previously insulated as described above is put on a special stand with centers like that used in spool winding.

The bobbin with the wire is placed on the base where it can turn freely. The wire gradually filling the recesses in the winding process

is pressed in with a nonmetal mandrel.

Winding must be done carefully; crossing the wire in the recesses and on the front parts of the winding must be avoided. Crossing the turns and tightening the wire insufficiently lead to a considerable increase in the size of the front parts, and when the last turns are wound into the recesses the winding has to be compressed very much. During the winding care must be taken that the insulation inserted in the recess is not displaced by the winding process, and that the wire is not laid beside the insulation.

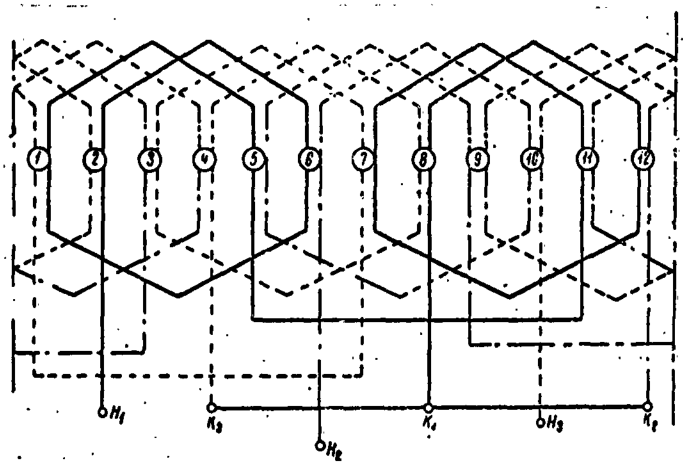


Fig. 67. Scheme of hand winding.

As hand winding is the same for nearly all gyromotor stators, we shall consider as an example the winding of a stator (Fig. 67) with the following data: 1) 3 phase; 2) 2 poles; 3) 12 recesses; 4) 4 sections per phase; 5) step on the iron – 4 (from the 1st recess into the 5th recess).

As in the case of spool winding, a prefabricated recess insulation is inserted into the recesses 1, 5, 2, and 6 of the stator pack which is fixed on the stand. An output terminal is soldered to the one end of the winding wire; the soldered junction is insulated with varnished fabric and put on the bottom of the second recess. Then the 1st

coil of the 1st phase is wound clockwise into the recesses 2-6. The wire is led over without a break to the first recess, and the second coil of the 1st phase is wound, also clockwise, into the recesses 1-5. The wire leading out from the fifth recess is cut off. In a way similar to that described above, the second output terminal is soldered to the winding wire and the recess insulation is inserted into the recesses 9 and 10. The soldered junction of the output terminal with the winding wire is fitted into the sixth recess, and the first coil of the second phase is wound into the recesses 6-10. After this, the wire is led into the fifth recess, and the second coil of the second phase is wound into the recesses 5-9. The coils are wound clockwise. The wire leading out of the tenth recess is cut off.

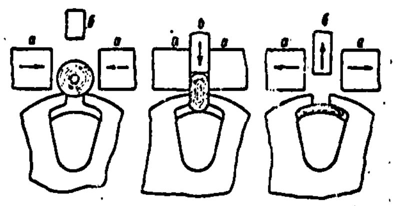


Fig. 68. Scheme of mechanical mounting of windings into the recesses.

In the same way, the third output end is soldered to the wire and the recess insulation is inserted alternately into the recesses 7, 3, 8, and 4 during the winding process. The insulated soldered junction is packed into the 10th recess. The 1st coil of the 3rd phase is wound into the recesses 10-2, the wire is led into the 9th recess, and the 2nd coil of the 3rd phase is wound into the recesses 9-1. The wire from the 1st recess is led without a break into the 7th recess, and the 3rd coil of the 3rd phase is wound into the recesses 7-3. Also without a break, the wire is led into the 8th recess, and the 4th coil of the 3rd phase is wound into the recesses 8-4. The 3rd and 4th coils are wound counterclockwise. The wire emerging from the 4th recess is cut off; it serves as a terminal for the winding of the 3rd phase.

Further, the winding wire is soldered to the clipped end of the 2nd coil of the 2nd phase which leads out of the 9th recess. The 3rd

coil of the 2nd phase is wound counterclockwise into the recesses 3-11. The wire is then led from the 11th recess into the 4th, and the 4th coil of the 2nd phase is wound into the recesses 4-12. The wire emerging from the 12th recess is cut off.

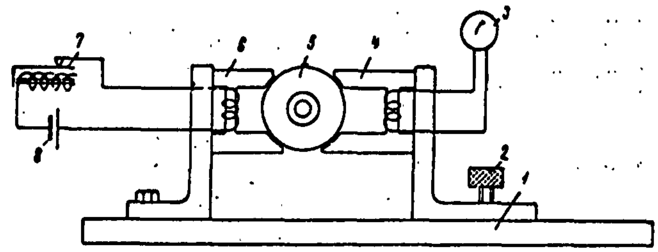


Fig. 69. Device for detecting short-circuited turns in the winding. 1) Base; 2) screw; 3) galvanometer; 4) movable electromagnet; 5) stator; 6) fixed electromagnet; 7) buzzer; 8) battery.

Winding wire is soldered to the clipped wire end leading out of the 5th recess. The 3rd coil of the 1st phase is wound into the recesses 11-7, then the wire is led from the 7th recess to the 12th, and the 4th coil of the 1st phase is wound into the recesses 8-12. The wire leading out of the 8th recess is cut off. The 3rd and 4th coils of the 1st phase are wound counterclockwise.

The clipped ends of the winding wire are bared, and the ends of the phases leading out of the recesses 4, 8, and 12 are connected to a star junction and soldered together with tin solder and rosin. In some cases, the ends between the 2nd and 3rd coils of the 1st and 2nd phases are not soldered and connected together in the winding process, but the coils are connected and soldered together with the phases being soldered into a star junction. All soldered junctions are carefully insulated with varnished fabric and fixed to the front part of the winding.

This order of winding the phases, namely that half of the first

phase is wound, then half of the second and all of the third phase, and only then the rest of the second and first phases, is used in order that the length of the wire be the same in all three phases. Consequently, the ohmic resistance of the phases will also be uniform. The uniform length of wire in all three phases is due to the fact that the coils of the first phase which are wound first and whose wire is very short are connected to the coils which are wound last and which have a very long wire. The coils of the second phase wound to the front parts of the winding of the two coils of the first phase are longer, and therefore the second to last coils are connected to them; in this way nearly the same length is reached as with the coils of the first phase. The coils of the third phase are wound to the front parts of the four coils, and therefore the third phase is wound on in one operation. With such a winding combination it is possible to obtain nearly the same length of wire in all three phases, and, consequently, also the same ohmic phase resistance.

After the wire has been wound into all recesses, the ends of the insulation projecting from the recesses are clipped and put into the recesses in such a way that they overlap. After this, Getinaks wedges are inserted into the recesses on top of the insulation by hand, just as in spool winding.

In the mass production of small-size electrical machines one cannot stop to insert recess wedges. In such machines a cord rolled from a paper strip is being used successfully. Thick cable paper is used for this cord. The fitting into the recesses is done by an automatic machine (Fig. 68). The machine cuts off a piece of paper, compresses it between two jaws a to the width of the slit and then presses it into the recess with a punch b. Owing to the elastic force and the pressure of the winding in the recess, the cord becomes oval, and so

closes the slit.

After the winding has been laid in position, its front parts are compressed. However, sizing must be carried out with due allowance for an increase in size after impregnation. Thereafter, the ohmic resistance of the winding and the resistance of the insulation of the winding relative to the iron of the pack are examined. A special device (Fig. 69) is used to make sure that there are no short-circuited turns. This device consists of two movable horseshoe electromagnets 6 and 4 composed of transformer iron plates and mounted in a vise. Spools with thin wire wound on them are fitted on the iron. The ends of the iron of the electromagnet are cylindrical and embrace the stator. One electromagnet is stationary and fixed on the base of the device, the other is freely movable. During the test, the coil of the stationary electromagnet is fed with the high frequency from the buzzer 7 which is supplied from the battery. The galvanometer 3 is included in the circuit of the coil of the movable electromagnet. The stator winding is tested for short-circuited turns as follows.

The stator to be examined with its winding has one side of its iron pack pressed against the cylindrical part of the bore of the stationary electromagnet. The movable electromagnet is moved to the other side of the stator pack and fastens it. The coil of the stationary electromagnet is supplied from the buzzer. The stator is turned by hand in the bores of the electromagnets. When the stator winding has no short-circuited turns no voltage will be induced in the coil of the movable electromagnet and the galvanometer needle will remain at zero. If there are shorted turns in the stator winding the magnetic field produced by the stationary magnet will intersect with the shorted stator turns and induce a current. The latter produces a voltage in the coil of the movable electromagnet, which makes the galvanometer

needle deviate from its initial position. The device makes it possible to detect one short-circuited turn in a winding.

§40. MACHINE WINDING OF STATORS

At present there are several machines on which gyromotor stators can be wound. The winding machines which exist can be distinguished according to their principle of operation: machines with the stator rotating, and machines with the stator stationary and a rotating wire spool.

In any technique of machine winding of stators an important part is played by the recess insulation and its fitting. The best way of fitting the recess insulation in stators that are to be wound mechanically is, as was shown above, continuous recess insulation. The reason is that this method does not interfere with the directing sidepiece of the machine during fitting and also eliminates the possibility of wire falling down in between the wall of the recess and the insulation.

Machines with Rotating Stators

In machines of this type the stator to be wound is on a mandrel which is put in the bush, and is clamped between special centers on the face plate which is on the front shaft of the machine. As the stator revolves, the wire is wound onto it from a spool clamped on the centers with a special tightening mechanism mounted on the chuck frame in the machine. These machines are the ones most widely used.

A [Soviet] institute has worked out a series of winding machines which can be recommended for stator winding in factories producing gyromotors. One of these machines is shown in Fig. 70. It is a universal machine on which not only stators with external straight and slanting recesses but also ordinary spools can be wound.

The fundamental processes, namely, laying the wire in the recess, reading and control of the given number of wire turns in the recess,

and shutdown of the machine after all sections have been wound, are mechanized. The auxiliary processes (pulling out and clipping of the wire, turning of the pack by one step of winding, releasing and removing the directing sidepieces from the pack when it is being turned) are performed by hand.

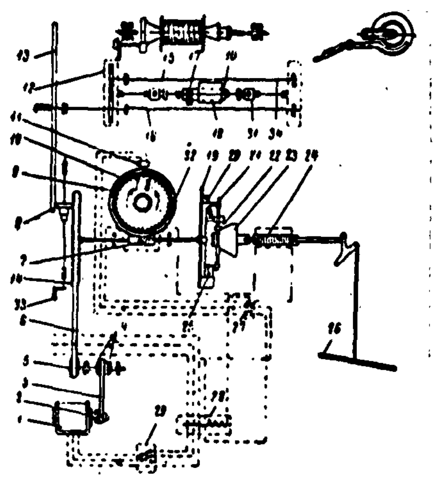


Fig. 70. Schematic diagram of the winding machines with a rotating stator.

When the machine operates, the taut wire slides along special directing sidepieces into the recess of the stator which is fastened on the chuck. The wire is wound on the stator in whose recesses a continuous recess insulation has already been placed by a special machine (described above). The machine consists of: 1) a base to which all parts are mounted; 2) a mechanism for the stepwise distribution of the wire; 3) an accessory for clamping the wire spools and controlling the tension of the wire during the winding process; 4) electric drive.

The machine is mounted to a wooden table. The headstock and tailstock which hold all the fundamental parts are mounted on a cast-iron plate.

The headstock carries the main driving shaft with the pulley 14 on one end, and the face plate (chuck) 19 with the centers 25 and 21 on the other. The stator 22 to be wound is clamped on the centers using the mandrel with center holes which is placed in the hole in the bush. The headstock of the machine also carries the wheel for the indicator of the number of turns, 10, whose wormwheel is in mesh with the worm 7 on the main shaft of the machine. On the tailstock of the

machine the rear shaft is mounted on bearings; on one end of the former the directing sidepieces 23 can revolve freely, and on the other end there is a link connected by means of a pull rod to the pedal 26, which is mounted under the table. Using this pedal one can remove the directing sidepieces from the stator pack when the latter is turned on for one step of winding. The tailstock is fixed in a recess of the base and is fastened by a hand lever. The mechanism for the stepwise laying of the wire consists of two guide screws 15 and 16 turning in opposite directions, and a reversing nut 18 with the guiding piece 17 and the setscrew 30. The guide screws are set in motion by a couple of pinions, 12, rigidly fastened to their left ends. At the end of one of the guide screws there is a friction disk 13 to which the rotation is transmitted from the driving pulley 14 by a movable rubber roller 8 between the friction disk and the driving pulley.

The speed of the guiding piece 17 and the step of wire distribution are adjusted by the speed of rotation of the friction disk 13 which is determined by the position of the rubber roller which can be set with the handle 33. When the handle 33 is turned a needle moves together with the rubber roller indicating on a scale the step of wire distribution adjusted.

The stops 31 on either side of the carriage 34 are used to set the motion of the guiding piece in accordance with the breadth of the coil to be wound.

The mechanism holding the spools of wire consists of a carriage with two centers; these support conical steel plugs holding the spool. The left plug has a braking disk seizing a brake shoe. The pressure of this shoe on the braking disk and the tension of the wire when it is wound are adjusted by a lever. The lever fixes the twist of a spiral spring whose end presses the brake shoe to the braking disk. The mova-

ble lever of the tightening fixture with the two tightening rollers is fastened to the axle of the carriage. The movable lever is linked to the brake shoe with a spring; so when the tension of the wire running through the guiding rollers increases, the lever will move down thus drawing the brake shoe out and reducing the braking of the spool and hence the tension of the wire. The carriage with the tightening fixture is mounted to a brace which is fastened to the machine table.

The electric drive consists of a magnetic starter 28 and the electromotor 1 which has a power of 0.25 kw, and works at 1400 rpm. The electromotor can revolve in both directions. There is a two-way switch 29 in the circuit of the motor to change the direction of revolution of the electromotor. The microswitch 11 is inserted in the feed line to the electromotor to turn the machine off automatically after a given number of turns has been wound into the recess of the stator.

The revolution of the pulley attached to the electromotor 2 is transmitted with the V-belts 3 and 6 to the pulleys 4 and 5 on the front shaft of the machine.

The machine is adjusted by inserting a coil with wire of the desired diameter between the centers of the tightening mechanism and by setting the wire tension required by pressing the brake shoe to the braking disk or by drawing it back. The mechanism for the stepwise distribution of wire is disconnected by disengaging the rubber roller and the friction disk 13 with the handle 33. The lateral guides 23 are set up to conform to the stator winding step. They are pressed apart by the pedal 26. The stator with its continuous recess insulation, 22, is fastened with a mandrel which is put in the hole of the bush, between the centers 21 and 25.

The pedal 26 is then released. As a result, the directing sidepieces 23 are pressed to the stator pack by the spring 24 on the tailstock. The sidepieces have already been set for one step of the wind-

ing on the recesses. The wire from the spool is led over the guiding piece 17 into one of the recesses and fastened to the face plate. After this, the feeder and indicator 10 is set to the given number of turns for the section.

After the machine has been adjusted the starting button 27 is pressed, and through the pulley and the belt transmission the electromotor begins to turn the pulley 14, situated at the opposite side of the driving shaft, with the face plate 19. The face plate revolves together with the fastened stator 22. It carries the directing sidepieces 23, and winds the wire onto the stator. Over the directing sidepieces 23 the wire slides into the stator recess. The worm 7 which is fastened rigidly to the shaft of the machine drives the wormwheel 10. The latter revolves together with the dial 9 of the feeder and indicator of the number of turns. The feeder 32 is set on the desired number of turns. As soon as the winding of a section is finished this feeder presses the button of the switch 11, disconnecting the magnetic starter 28 and the electromotor 1. The face plate 19 with the stator is stopped, the wire is thrown on the loop stand 20, and then the directing sidepieces 23 are removed from the stator with the pedal 26. The stator is turned by hand for one winding step, and the wire is put into the corresponding recess of the stator. By releasing the pedal the stator is fixed with the sidepieces 23 in the position required for the winding of the subsequent section. The button turning on the electromotor is pressed and the following section is wound. After the last section of the stator has been wound the directing sidepieces are drawn aside by pressing the pedal 26, and the stator with the winding is taken out from between the centers.

When the sections for stator spool winding are wound, a spool is mounted on the face plate instead of the centers, the directing side-

pieces are removed, and a mechanism for the stepwise distribution of the wire is inserted.

The machine is simple and can be used successfully in the mass production of gyromotors with stators having a low coefficient of recess filling, and with windings that are not bounded by front parts.

Winding stators which have a high coefficient of recess filling and are bounded by front parts is difficult and in some cases impossible with such a machine.

Figure 71 shows a schematic diagram of the winding machine. A guiding jaw is attached to the face plate, which embraces the stator pack round the outside. The second half of the guiding jaw is on the tailstock of the machine where it catches the second half of the stator pack diameter. The jaw is pressed to the stator pack by a spring and is removed by pressing the pedal of the machine (not shown in the diagram).

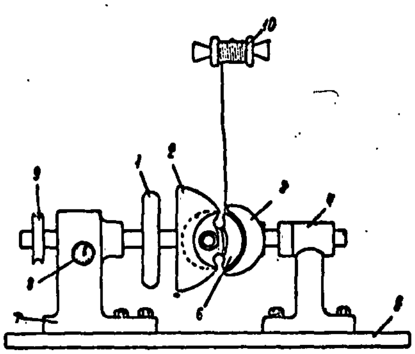


Fig. 71. Schematic diagram of the winding machine with jaws. 1) Face plate; 2) fixed jaw; 3) movable jaw; 4) tailstock; 5) base of the machine; 6) stator pack; 7) headstock; 8) indicator; 9) driving pulley; 10) spool with wire.

The spool with the wire is fastened and the tension is adjusted as in the machine described above.

As the stator revolves the wire falling into the plane of the jaws skims over their surface, slides down, and falls into the recess of the stator. As to the rest, the winding is done as in the machine described above. Winding on this machine has one shortcoming, namely, that the wire on the front parts piles up in one place on the bush of the stator. The wire of all the sections has a tendency to pile up towards the center around the bush or axle, and the front parts of the windings increase considerably in size.

The author has designed a machine (author's certificate No. 52465) which also regulates the packing of the wire on the front parts in the winding process.

This machine differs from that described above in that the wire is packed into the recess without sliding down. The stator recesses with their slits are led to a stationary roller carrying the wire which then is always laid into the middle of the recess. A hook on the bush is used to pack the wire on the front parts.

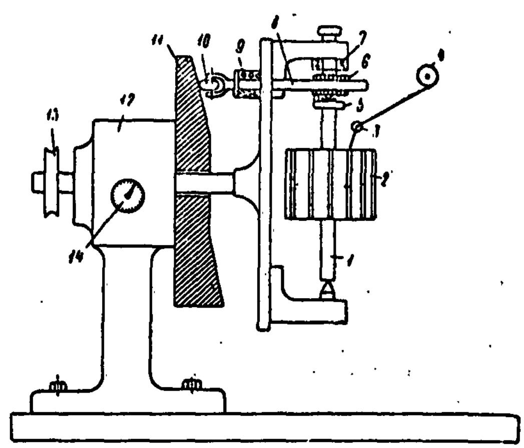


Fig. 72. Schematic diagram of the machine with a winding cam plate. 1) Mandrel; 2) stator; 3) ear; 4) spool with wire; 5) ratchet wheel; 6) pinion; 7,9) springs; 8) rack; 10) roller; 11) distributing cam plate; 12) headstock; 13) pulley; 14) indicator.

The machine (Fig. 72) comprises special centers which hold the stator 2 by its mandrel. A pinion 6 with a projection pressed down by the spring 7 is attached freely to one center. A ratchet wheel 5 with the same number of teeth as there are recesses in the stator is mounted firmly on the mandrel of the stator. The pinion meshes with the rack 8 which goes through the base of the centers and is pressed away from them by the spring 9. At the end of the rack is a roller 10

which is forced to move according to the cam plate fastened to the stationary face plate 12 of the machine.

The stators are wound on the machine as follows: the wire is led from the spool 14 through the ear 3, which is fixed at a definite place, is inserted into the first recess of the stator which has received its continuous recess insulation before, and is fastened to the end of the mandrel. Then the machine is set in motion. The roller begins to roll along the cam plate 11 specially designed for the given type of stator and thus moves the rack. In turn, the rack turns the stator around its axis by means of the pinion with the projection so the slit of the recess always faces the ear with the wire. If the recess is straight the cam plate will turn the stator only on its front part, packing the wire against the bush. In the case of slanting recesses the top of the cam plate must be higher than the lower part by the amount of the slant of the recess. The cam plate must be such that on two-pole as well as on four-pole stators the wire lies always in the middle both when it enters and leaves the recess. After the first spool has been wound into the corresponding recesses, the pinion is lifted up so that its projection releases the ratchet wheel. The stator is turned through the following recesses corresponding to one winding step. The machine is set in motion and the second spool is wound into these recesses. The other spools of the winding are wound similarly.

The additional operations, namely fastening the ends of the winding, turning the stator to the following recesses, inserting and taking the stator out of the machine, are done by hand.

Machines with the Stator Fixed and the Spool with the Wire Turning

In machines of this type the stator is fastened on a mandrel between centers that are fixed on the tailstock of the machine. The

spool with the wire is fastened to the face plate of the headstock of the machine, which is on the shaft of the machine. The spool with the wire is held in a special brace with a tightening mechanism. The wire runs through the hollow shaft of the headstock of the machine, guided by a roller (Fig. 73).

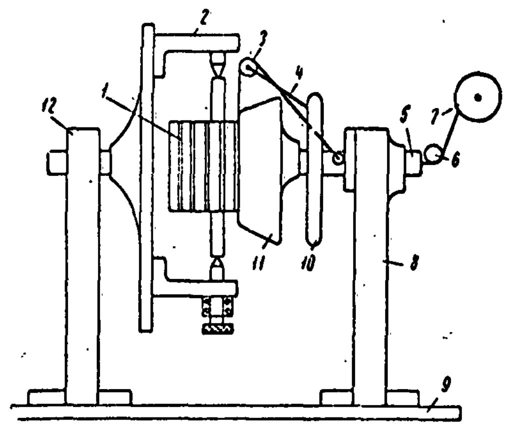


Fig. 73. Schematic diagram of the machine with stationary stator. 1) Stator; 2) centers; 3) roller; 4) arm; 5) hollow shaft; 6) roller; 7) spool with wire; 8) headstock; 9) base of machine; 10) pulley; 11) guiding sidepieces; 12) tailstock.

Winding is carried out as follows: the stator 1 with its continuous recess insulation previously installed is placed between the centers 2 which are mounted to the tailstock of the machine, 12. The guiding sidepieces 11, mounted on the stand 8, are adjusted according to the recesses of the stator. The wire from the spool 7 runs over the roller 6 and through the hollow shaft 5 of the headstock. The roller 3 with the arm 4, which is fastened to the pulley 10, is put into the recess of the stator and is fastened on the mandrel. The machine is then set in motion. The pulley turns the arm with the roller 3 and entrains the wire which slides into the stator recess over the sta-

$$B_1 = B\frac{b}{l}, \quad B_2 = B\frac{l-b}{l},$$

where a is the distance from one end of the cylinder to the location of the vector of the centrifugal force A; b is the distance from the second end of the cylinder to the location of the vector of the centrifugal force B; and l is the distance between the ball bearings.

The directions of the vector components A_1 and A_2 and the vector components B_1 and B_2 are the same as those of the vectors A and B. Consequently, expanding the radial forces yields A_1 and B_1 in the first end plane and A_2 and B_2 in the second end plane. Geometrical addition of these forces yields two resultant forces R_1 and R_2 located in the two end planes, equal to the centrifugal forces $\bar{A}$ and $\bar{B}$ in magnitude and direction.

Therefore, if more than two unbalanced centrifugal forces are assumed then these forces can be resolved into components lying in the cylinder end planes, and all of them can be reduced to two equal unbalanced centrifugal forces applied to two arbitrary noncoincident planes perpendicular to the axis of revolution of the cylinder.

To achieve dynamic equilibrium it is necessary to apply balancing weights G_{u1} and G_{u2} to the diametrically opposed forces R_1 and R_2; the former exert centrifugal forces C_{u1} and C_{u2} equal in modulus and opposite in direction to the resultant forces R_1 and R_2.

The problem of dynamic balancing of cylindrical bodies is to find the size and location of the balancing weights whose attachment produces centrifugal forces equal and opposite to the unbalanced forces producing cylinder vibrations during rotation and destructive loads in the bearings. At equilibrium of these forces, the forced vibrations of the cylinder vanish.

In dynamic balancing the cylinder is balanced first at one end

tionary guiding sidepieces. After the required number of turns from the first spool has been wound on, the machine is stopped, the guiding sidepieces with the fixing pin (not shown in the diagram) are pressed away so the latter no longer protrudes into a recess, and the stator is turned on to the next recess.

All the auxiliary processes are performed by hand: preparing the ends of the stator winding, turning and pressing away the sidepieces, inserting the stator into and removing it from the machine.

An advantage of the machines with stationary stators is the possibility of observing visually each turn of wire as it is wound into the recess.

After the required number of turns has been wound into all recesses, the stator is taken out of the machine, the insulation between the slits is cut off and fitted into the recesses. On the insulation Getinaks wedges are placed in the recesses, and all ends of the phases are connected to a star junction. The soldered junctions are insulated and packed into the winding on the front parts.

Several foreign firms use winding machines with stationary stators made by the "Globe" Company for winding gyromotor stators. The stator is fixed on a mandrel which is fastened in the center of an index dial in the machine. The stator recesses are in contact with a special catch embracing the stator over one step on the iron. A guiding piece with a roller over which the wire from the spool is directed to the sidepieces of the catch is mounted to the flywheel of the machine. As the machine turns, the wire from the spool falls on the roller of the guiding piece, from there onto the sidepieces of the catch, and from these slides directly into the recess. When the required number of turns has been wound into the recess the machine stops automatically and the index dial is turned, thus turning the

stator through the required number of recesses. The machine is then set in motion again and winds the next coil into the other recesses, and so on, until all the coils of the stator are wound.

The stators wound in machines go through the same additional operations and controls as in hand winding. After these, they are given to the impregnating department for impregnation of the winding with insulation varnish.

§41. IMPREGNATION OF THE STATOR WINDINGS

As was described above, class A insulating materials and in some cases fluoroethylene-4 whose properties are similar to those of class B materials are used in gyromotors for insulating the stator windings from the body. Class A insulations are porous and hygroscopic. Fibrous insulation materials have an insufficient heat resistance and a low thermal conductivity. Between the individual turns and sections of the winding there are always air gaps and interlayers. To eliminate these shortcomings the stator windings are impregnated with an insulating varnish after they have been wound. The idea of insulating the windings is to create a strong electrical insulation between individual turns and between the turns and the body, corresponding to the dielectric quality of the varnish which is used for the impregnation. Moreover, the impregnation of windings with fibrous insulating materials should:

1) increase the mechanical strength of the winding, since the evaporated varnish cements the turns together and forms a uniform mass after impregnation;

2) increase theresistance to moisture, because the impregnating varnish fills the pores and gaps in the winding and insulation preventing moisture from penetrating;

3) improve the heat conductivity of the winding, since the air

in the pores of the insulation and between the wires is displaced by a varnish film which is a good heat conductor;

4) increase the heat resistance of the insulation, since the varnish slows down the oxidation processes in it.

Essentially, the process of impregnation consists in previously removing all traces of moisture and air from the pores of the insulating material and from the air gaps between the wire and the insulation, and in filling them with insulating varnish. For this purpose one has to make sure that the impregnating varnish penetrates well into the pores of the insulation and into the gaps and voids between the windings. Therefore, impregnating varnishes should meet the following fundamental requirements:

of having good dielectric properties at both normal and increased temperature and humidity;

of rapidly soaking into all macroscopic and microscopic pores on impregnation, i.e., of having a high impregnating quality;

of filling as many as possible macroscopic and microscopic pores and capillaries, or all those that are open;

of solidifying as fast as possible after the pores and capillaries have been filled;

of not softening at working temperatures after solidification;

of being elastic;

of having a high heat conductivity;

of having no destructive effect on copper, iron, electric insulation materials, and enamel insulation of the winding;

of adhering firmly and establishing a firm connection between the turns and between the individual layers of the winding;

of being highly moisture-resistant.

These properties can be found with many kiln-dried varnishes (Ta-

ble 10). The varnish chosen depends on the operating conditions of the windings and on the type of insulation applied to the wires.

One has to choose those impregnating varnishes in which neither the solvent nor the base would affect the insulating enamel of the wire. Windings of PEL, PET, and PEV wire are impregnated with asphalt-oil varnish No. 447 or with 321 varnish. Windings of PEV wire can be impregnated with cresol-oil varnish No. 9-627. Windings that are in contact with mineral oil are impregnated with GF-95 glyptal-oil varnish. For impregnating the stator windings in gyromotors with a PEL enamel insulation or with a PEV viniflex insulation, No. 321 varnish is used; this is a colloid solution of glyptal or pentaphthal resin modified with tung oil, or a mixture of glycerins, colophony, tung oil, subjected to polymerization in volatile organic solvents with addition of siccative. The hue of the varnish is usually not normalized, the color must be yellow. The viscosity of the varnish, according to the NIILK standard funnel (nozzle 7), must not be less than 10 sec at a temperature of 18-20°C. The drying time of the varnish when applied to condenser paper must not exceed 2 hours at a temperature of 100-110°C. There must not be more than 40% nonvolatile substances in the varnish. The sparkover voltage of an 0.04-0.06 mm thick varnish film upon a copper plate after drying at 100-110°C for 6 hours must be: a) not less than 55 kv/mm at a temperature of 18-20°C, b) not less than 15 kv/mm at a temperature of 18-20°C after being kept in distilled water for 24 hours.

Coating varnishes are used to coat the windings after impregnation:

a) after impregnation with No. 447 varnish, No. 460 asphalt-oil varnish is used: this makes a strong protective film on the surface of the impregnated insulation and is resistant to moisture;

TABLE 10

Comparison of the Properties of Liquid Impregnating and Coating Dielectrics

1 Вид диэлектрика	2 Наименование лака или эмали (по основе)	3 Номер или обозначение	4 Разбавители	5 Температура сушки, °С	6 Время сушки, час.
13 Лаки	7 Асфальто-масляный	447	9 Смесь уайт-спирита и толуола; толуол; бензин	105	6—8
	8 То же	460		105	12—15
	Глифталево-масляный 10	ГФ-95 11	12 Смесь уайт-спирита и толуола; этиловый спирт; бензол; толуол	105	1,5—3,0
	Крезольно-масляный 14	9—627	Бензол; ксилол 15	105	0,3—0,5
	Глифталево-масляный 16	1154	17 Смесь уайт-спирита и толуола; бензин; бензол	105	2
	18 Глифталевый или пентафталевый	321	19 Смесь уайт-спирита и скипидара	100—110	6
	Бакелитовый 20	СБС-1 21	Этиловый спирт 22	115	3—5
	Кремнийорганический 23	ЭФ-3 24	Смесь бензина, скипидара, толуола 25	200	1—2
29 Эмали	Кремнийорганическая 26	ПКЭ-14 27	Бензол; толуол 28	200	2—3
	30 То же	31 ПКЭ-15	32 Бензол; толуол	200	1—2
	33 Нитроглифталевая	1201	Состав № 643 34	20	0,3—0,6

1) Form of dielectric; 2) name of varnish or enamel (acc. to base); 3) number of designation; 4) diluent; 5) drying temperature, °C; 6) drying time, hours; 7) asphalt-oil; 8) the same; 9) mixture of white spirit and toluene; 10) glyptal-oil; 11) GF-95; 12) mixture of white spirit and toluene; ethyl alcohol; toluene; 13) varnishes; 14) cresol-oil; 15) benzene; xylene; 16) glyptal-oil; 17) mixture of white spirit and toluene; benzine; benzene; 18) glyptal or pentaphthalic; 19) mixture of white spirit and turpentine; 20) bakelite; 21) SBS-1; 22) ethyl alcohol; 23) organosilicon; 24) EF-3; 25) mixture of benzine, turpentine, toluene; 26) organosilicon; 27) PKE-14; 28) benzene; toluene; 29) enamels; 30) the same; 31) PKE-15; 32) benzene; toluene; 33) nitroglyptal; 34) compound No. 643.

b) after impregnation with No. 321 varnish the winding is coated with the same varnish one or two layers thick;

c) after impregnation with GF-95 varnish, No. 1201 nitroglyptal enamel drying in air is used. The enamel is used for coating the metal surfaces which must be insulated and protected against corrosion.

Stators having windings with heat-resistant insulations that are intended for work at high temperatures are impregnated with varnish having a higher heat resistance. The organosilicon varnishes developed under the supervision of K.A. Andrianov belong to that group of varnish. Organosilicon varnishes are characterized by their high heat resistance. They can withstand a temperature of 200°C for a considerable time, and for a short time even 230-250°C. Under these conditions, they retain their high mechanical and dielectric qualities. These varnishes are moisture-resistant. The organosilicon varnishes EF-3 and K-4s, and the enamels PKE-14 and PKE-15 are those used most.

The technical process of impregnating the stator windings of gyromotors with No. 321 varnish consists of the following steps.

Previous Drying

After the electrical parameters of the winding have been checked the stators are cleaned of dust and other contaminants with an air blast or with a brush. The ends leading out are lubricated with castor oil, and the stators are put on racks in drying chambers. Drying in drying chambers which are thermally insulated on the outer surfaces is carried out by convection by means of electric heating for which purpose heaters are in the chamber. Forced air circulation with automatic temperature control within the range of 105-110°C is used to accelerate the drying process.

Recently, chambers with induction heating have been used largely for drying the windings before and after impregnation. Drying in such

chambers is brought about, together with the convection of heated air emerging from the heated walls of the chamber, by the heat arising in these very parts under the action of eddy and hysteresis currents produced by an alternating electric field. Such chambers are safe with regard to fire, have a uniform temperature over their entire volume, are relatively durable, and require much less energy than chambers with resistance heaters.

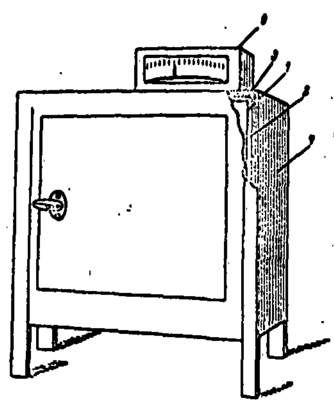


Fig. 74. Induction drying chamber. 1) Inner steel frame; 2) insulating coat; 3) winding; 4) outer facing; 5) temperature control device.

Figure 74 shows the induction chamber, which consists of a welded frame 1 insulated with asbestos sheet 2 on the outer surface and which has a special winding of insulated copper wire 3. The chamber is faced on the outside with a heat-insulating material. For this purpose tiles 4 are usually employed which are fastened to corner irons welded to the frame. Inside the frame there are grills on which the stators or other parts to be dried are put. The chamber is closed tightly with doors. The winding of the chamber is supplied with alternating current direct from the mains.

The stator windings are dried preliminarily for 2-2.5 hours at 105-110°C.

Without being cooled, the stator windings dried in the chamber are put into an autoclave heated to 70-80°C which belongs to the vacuum impregnation equipment (Fig. 75). There they are dried additionally in vacuo so that the moisture is removed quickly and completely. On this occasion not only the moisture but also the air is extracted from the pores.

The vacuum impregnation equipment consists of an autoclave 1 and a preparatory boiler 9 which serves as a mixing tank. The autoclave can be sealed with a hermetic lid 2, and the mixing tank with another lid 8; both lids are hinged. The tube 11 connects the autoclave to the preparatory boiler, and the tube 6 connects it to the compressor 7, the vacuum pump 3, the tube 5, and the condenser 4 along whose walls cold water runs, condensing the moisture evaporating in the chamber when the article is dried. The tube 11 includes a stopcock 10 which is to feed the varnish into the autoclave during the impregnation and back into the mixing tank after impregnation. The air and the moisture

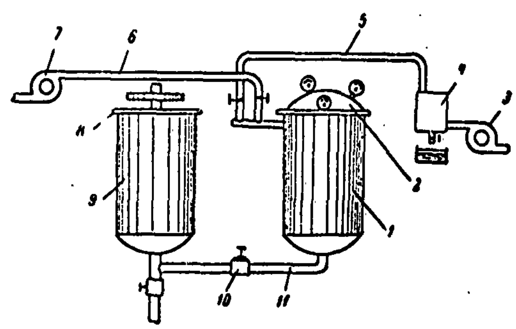


Fig. 75. Vacuum impregnating equipment.

evaporated when the part is dried in the autoclave are pumped out by the vacuum pump, and the compressor applies a pressure to the varnish in the autoclave when the piece is impregnated which enables the varnish to penetrate into the pores that were opened during the desiccation. Thus, the preparatory boiler of the autoclave is a kiln for vacuum drying of the windings before impregnation and also a boiler for impregnation under pressure. The mixing tank serves as a reservoir in which the varnish is diluted with a solvent until the required viscosity is reached, heated, and mixed with a stirrer fastened to the lid.

The boilers are heated electrically; the heaters are immersed in oil which washes the outer surface of the boilers. The impregnating and mixing boilers are equipped with control and measuring instruments: a manometer, a vacuum gage, thermocouples etc.

Vacuum drying of the stator windings in the autoclave is carried out at a temperature of 60-70°C for 1-1.5 hours; the vacuum is not less than 720 mm Hg. Such an additional vacuum drying of the windings makes it possible to remove almost completely all air and moisture from the macro- and micropores of the insulation and from the gaps between the wires.

Vacuum Impregnation with Varnish

After the vacuum drying, half an hour before the varnish is let in, the heating of the autoclave is turned off so the temperature of the windings subsides. The varnish in the mixing tank is heated to a temperature of 50-60°C and agitated continuously with a stirrer. Without reducing the vacuum one opens the stopcock in the tube and drives the varnish under atmospheric pressure from the mixing tank into the autoclave. The varnish level must be approximately 50 mm higher than the level of the parts supplied. After this the cock is shut. Before the varnish is let into the autoclave the vacuum pump is shut off and the cock of the air lead is bridged over.

The vacuum at a temperature of 60-70°C remaining in the autoclave after the varnish intake has ceased is kept up for 5-10 min; then the pressure is increased up to atmospheric pressure, and the part is kept under this pressure and at the same temperature for another 5-10 min. The compressor is turned on, the stopcock in the air lead is opened. The pressure in the autoclave is increased to 3-4 atm and kept there for 15-30 min. The temperature of the varnish must not be less than 60-70°C. Under such a pressure, the varnish will penetrate into all

pores and gaps of the insulation and stator winding. In the course of 15-30 min the pressure in the autoclave is reduced to atmospheric pressure, the cock in the varnish supply line is opened, and the varnish from the autoclave is led into the mixing tank. After all of the varnish has gone into the mixing tank, a process observed through a glass in the autoclave lid, the lid is kept shut for another 30 min while the cock in the varnish pipe is kept open so the remaining varnish will run off from the stators; only then is the cock shut.

Thereafter, the vacuum pump is turned on, the cock in the air lead is opened, and the air containing the vapors is pumped out of the autoclave so that an underpressure of not less than 720 mm Hg is produced in the autoclave. At this pressure and a temperature of 70-80°C the impregnated stator windings are vacuum-dried for 2-3 hours. After this procedure the lid of the autoclave is opened, the stators are taken out, and the metal parts and cable ends of the stator windings are rubbed with a pad soaked with white spirit or benzine to remove the varnish.

The stators are placed on a rack and dried in air for 2 hours at a temperature of 17-25°C. The cable ends of the winding are lubricated with castor oil, and the stators are put on racks in the drying chamber where they are dried for 30-45 hours at a temperature of 105-115°C. The stains on the iron surface are removed, and the stators are again put into the autoclave without being cooled. The autoclave lid is shut and the cycle of impregnating and drying the stators is repeated. The quality of drying is checked by measuring the resistance between the winding and the frame. All the stators are taken out of the chamber and are checked with a 500-volt megger at a temperature of 90-100°C. The resistance of the insulation must not be less than 100 megohm. When the resistance of the insulation is less than 100 megohm, the

stator windings have to be dried further under the same conditions until the resistance of the insulation has reached the required value.

To check on good drying of the varnish in the depth of the winding, the method of spatter is used. For this purpose the stator is pushed with the hole in its bush on the shaft of a stand, fastened, and covered with a hood. Then an electromotor is turned on which turns the stator at a speed of 3000-3500 rpm for 1-3 min. If the varnish is not dry enough it will fly off the winding, atomizing and covering the inner surface of the hood as the stator revolves.

After impregnation and drying, the front parts of the winding must be covered completely with a varnish film of brilliant brown color which forms a solid monolith. When there are individual turns or full sections left over, it is necessary to apply the same varnish additionally by immersion or with a brush and then to dry it in a drying chamber.

Finally, the impregnated and dried stator windings are tested for strength, ohmic resistance, and short-circuited turns by means of a special device shown in Fig. 65. With No. 321 impregnating varnish the viscosity and the specific weight are checked in the mixing tank before the impregnation. The specific weight must be 0.87-0.88, and the viscosity 6-10 sec according to VN-7. When these values are not observed the varnish is diluted at a temperature of 16-20°C with a mixture of 60% white spirit and 40% turpentine.

The double impregnation procedure for stator windings described above yields satisfactory results. In some cases, for extra tough windings, a triple impregnation is applied. Good qualities are obtained with impregnations under break-in conditions. These consist in producing alternately an under- and an overpressure in the autoclave during the process of impregnation.

After impregnation of the stator windings with organosilicon varnishes, the stators are dried at a temperature of 180-200°C if the recess insulation and the insulation of the wire itself allow this to be done.

§42. SHEATHING OF THE WINDINGS WITH PLASTIC

As can be seen from the technical procedure described, one cycle of stator winding impregnation takes 4-5 days. Such a long impregnation procedure, although giving the required results, complicates the industrial process of manufacturing electrical machines, which also include gyromotors, in the case of series and mass production.

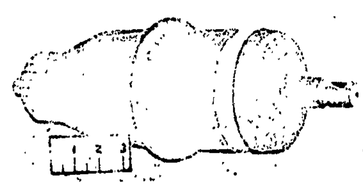


Fig. 76. Sheathed rotor of a commutator electromotor.

The author, together with the institute, carried out work in one of the factories, to replace vacuum impregnation by sheathing with plastic under pressure of the windings of small-size electrical machines working at variable temperatures and under increased moisture.

When such a technique is used to insulate the windings the process lasts only several minutes; this is important in series and mass production. In this case, the front parts of the windings have a plane, smooth surface (Fig. 76) which protects the winding from condensation of moisture, accumulation of dust, and mechanical damage. The difficulty of sheathing the windings under pressure instead of impregnating them consist in choosing a plastic which must have the following basic qualities:

– a good consistency, making it possible to carry out pressure sheathing under minimum pressure and ensuring that the space between the turns is filled out without doing damage to the winding;

- capability of being pressed in a cold form, which protects the enamel of the wire from being subjected to higher temperatures for a long time;

- high insulating qualities at increased and reduced temperatures;

- high resistance to water, protecting the winding when humidity is high;

- good adhesion to metals;

- high electrically insulating qualities that are stable under conditions of increased humidity, and high and low temperature.

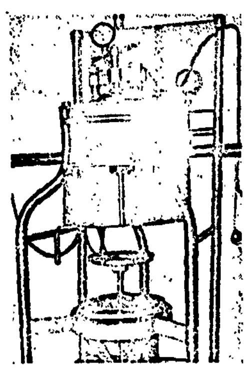


Fig. 77. Gas pressure sheathing device.

In the selection of the plastics it was shown that, when the windings are sheathed with plastics of thermosetting resins which require increased pressure and temperature, the test results of electrical machines give satisfactory qualities for all parameters. However, when windings with thin wire are sheathed the latter with break and the enamel will be damaged.

Plastics consisting of thermoplastic resins which require reduced pressure and temperature have much better molding properties and harden relatively quickly. As a result, the properties of the enamel of the wire are not impaired on sheathing, and breaks in the winding are not observed. But most of the thermoplastics have one important disadvantage, namely, that they soften when the windings are warmed up during operation to their working temperature, which reduces their physical and mechanical qualities.

Polyamide resins which do not have the shortcomings of the thermosetting and thermoplastic resins pointed out above are used. Poly-

amides melt at once, nearly like a metal, soften only slightly up to their melting point, and have a good yield and all the necessary properties indicated above.

For sheathing windings one can use polyamide resins – caprone, polycaprolactam-anide, polyamide 68, etc. However, when windings with a recess insulation of cardboard or varnished fabric are pressure sheathed, the resistance of their insulation will decrease on heating. To increase the resistance of the insulation of the windings in a hot state it is necessary to insulate the recesses with fluoroethylene-4 and to do the sheathing on a pressure device which ensures a uniform pressure.

The gas pressure device is shown in Fig. 77. The pressure is exerted by an inert gas. The plastic is placed in the melting pot of the device and heated to its melting point by means of a "Dowtherm" liquid heat carrier which fills the hermetic jacket of the melting pot.

The heat carrier, which is heated by electrical spirals in the lower part of the jacket of the pot, is vaporized, its vapor rises to the upper part of the jacket; there it heats the pot, condensing in the closed volume in such a way that the melting pot is heated gradually and uniformly. The top of the melting pot is sealed by a lid. In the lower part of the pot there are a nozzle leading to the press form, and a stopcock to admit the molten plastic into the press form.

The press form is placed on a lifting platform and connected to the nozzle of the melting pot. The latter is connected to a gas cylinder and is provided with a pressure gage, a safety valve, and a bush for a thermocouple or thermometer.

The pressure of the inert gas forced out by the molten plastic is constant; this is achieved by means of a reducing valve on the gas cy-

linder.

The use of pressure sheathing of the stator windings of gyromotors instead of vacuum impregnation makes it possible to improve the quality considerably, to reduce the time required for manufacture, and to perform a complex, strenuous, and lengthy technical procedure right on the assembly line.

§43. ANTICORROSIVE COATINGS

Metal, chemical, and varnish coatings are used to protect parts of gyromotors from corrosion and to give them a nice finish.

All-steel or half-steel parts and reinforcing pieces are coated with metal galvanic coatings. Steel pins retain their coating only on their shoulders; on all the other setting places the coating is removed by final polishing. Some foreign firms apply a metal coating to the rotors before the packs with the shunted windings are pressed to them. The steel parts of gyromotors and reinforcing pieces are coated with lustrous zinc or cadmium with subsequent passivation. The thickness of the layers varies from 10 to 30 μ in the case of zinc, and from 10 to 50 μ in the case of a cadmium coating. As passivating agents for the zinc and cadmium coatings aqueous solutions of chromium salts are commonly used, preferably sodium bichromate and sulfuric acid. Chromium anhydride and ammonium bichromate are also used for the same purpose. After the passivation, the surface of the part assumes an opalescent, pinkish-green or green color. Other hues have lower protective properties.

The current-carrying brass plates are finished with a tinplating to improve their soldering properties. The terminals and other current-carrying parts of gyromotors are nickel plated. Usually, lustrous nickel plating is employed. In some cases the current-carrying parts are silvered.

Metal plating of gyromotor parts is not specific and is therefore not considered.

§44. CHEMICAL COATINGS

A chemical coating is a thin, tough layer of the oxide of the metal of which the part is made. It is resistant to wear and protects the surface of the part against corrosion under the action of reactive agents. Chemical coatings are applied in the manufacture of gyromotors by anodic oxidation and passivation.

Anodic oxidation (anodization) is used for anticorrosive coatings to protect gyromotor parts made of aluminum, or aluminum and magnesium alloys.

The process of anodization consists in turning the surface layer of the metal into a more-or-less hydrated aluminum oxide under the action of the oxygen separated out at the anode. Three fundamental methods are used for anticorrosive anodization: chromate, sulfate, and oxalic anodization. These methods differ in the composition of the electrolytes, in the particular features of the formation of the film, and in the properties of the films obtained. Each of these methods has its advantages and disadvantages.

The technical process of sulfate anodization is described below. It gives good results with coating of gyromotor bodies and covers made of AL2 alloy, and of bearing nuts made of duralumin.

Before coating, the parts must be carefully degreased. Degreasing is done chemically, by placing the part in a tank containing 50 g/l trisodium phosphate, 5-10 g/l caustic soda, and 30 g/l water glass for 3 min at a temperature of 60-70°C. When the grease on a part cannot be removed by chemical degreasing, the part is washed first in a gasoline bath. Then the part is dried until the smell of gasoline has vanished completely, and is degreased chemically. After degreasing, the parts

are first rinsed with warm water of a temperature of 30-60°C for 1-2 min, and then with cold water under a shower for 1-3 min.

Before degreasing, rubber plugs are pushed firmly into the holes for the ball bearings in the bodies and covers, protecting these parts from contact with the electrolyte and from oxidation of the surface of the holes for the ball bearings.

After degreasing, the parts are purified by immersing them in a tank containing nitric acid of specific weight 1.3-1.4 at a temperature of 17-25°C for 0.2-0.5 min. The purified parts are rinsed with cold water for 1-3 min.

The process of anticorrosive oxidation is brought about by leaving the part for 40-60 min in a tank with sulfuric acid of specific weight 1.84, diluted to 150-200 g/l in water at a temperature of 15-26°C.

During the oxidation a voltage of 12-24 v is applied, the current being regulated according to the calculation providing 2-2.5 a per part. The electrolyte must be agitated with compressed air throughout the process. After oxidation, the parts are rinsed for 3-10 min in cold water, then for 3-10 min in hot water at a temperature of 60-90°C. The absence of sulfuric acid on the surface of the parts is checked on one part taken from each rack by applying one drop of methyl orange to the surface of the part; the drop must not turn pink.

A porous oxide layer forms on the surface of the parts during the oxidation in sulfuric acid. The layer has a high adsorptive power owing to the freshly formed oxide. This property is also used to increase the protective quality of the film and to give it a decorative appearance by means of the methods of "filling." Thus, when a part previously subjected to the action of sulfuric acid is treated in a bichromate solution (consisting of 100 g/l potassium bichromate and 18

g/l sodium carbonate) by placing the part in the electrolyte at a temperature of 70-90°C for 2-10 min, the film will become saturated with passivating bichromate ions. The corrosion resistance of the film is considerably increased in this way.

The parts treated with bichromate are rinsed first in cold and then in hot water for 1-3 min, taken from the racks, and put into the drying chamber where they are dried for 10-15 min at a temperature of 100-120°C.

To increase the corrosion-protective property of the oxide layer, which readily adsorbs fats, an oil layer is applied by placing the part in MVP vaseline oil heated to 110-115°C. Then the surface of the part is wiped with gauze. The dimensions of the part remain practically unchanged on oxidation.

Magnesium alloys are oxidized by three fundamental methods: in selenic acid, and in alkaline and in neutral media. The last two methods of oxidizing gyromotor parts are hardly ever used since they cause the dimensions of the oxidized parts to change considerably.

The oxidation of magnesium alloys with selenic acid is used as a separate coating for gyroscope parts since the process does not change the dimensions. But the corrosion resistance of the film is not very high. To increase resistance to corrosion, the oxidized parts are greased with neutral lubricating greases.

§45. VARNISH COATINGS

Varnish coatings are varnish films applied to the surface of the parts which protect these from corrosion and give them a nice appearance. They are used for parts of gyromotors that have a size with relatively great tolerances and which are not subject to tough mechanical influences and heating above 200°C.

Varnish and oil coatings are applied to gyromotor parts by three

methods: with a brush, by dipping the part into a tank, and by spraying.

Coating with a brush gives the least waste of material, but this method is not efficient. It is used to coat the outer surface of the stators, to paint the inside of the rotors with No. 1154 varnish, and to apply an anticorrosive lubricant to the setting places of the pins, adjacent to the body. It is also used to paint the surface at places which are difficult of access and to draw inscriptions and designations.

Dipping of the parts or of their surface into a tank is used when they are to be coated with a fatty lubricant for anticorrosive conservation between operations.

Spraying consists in delivering varnish and compressed air from two channels into the jet of the sprayer. At the outlet of the jet the varnish is carried along with the pressurized air and settles on the part in the form of dust. The varnish can be supplied through a tube from a special machine to the sprayer, or can issue from a container fastened to the sprayer.

The quality of the varnish coating depends on the quality of the material and on the technique of applying the varnish. An insufficient preparation of the surface to be painted can lead to a flaw during the painting of the parts.

To protect the surfaces of the stator packs and of the rotors of the gyromotors from corrosion they are coated with No. 1154 glyptal oil insulating varnish which is furnace-dried, and whose fundamental properties are shown in Table 10. A one-to-one mixture of white spirit and toluene is used as a solvent for this varnish.

Painting of the Stator Packs

After their final grinding, the stators are painted. Before

painting, dirt and dust are carefully removed from the recesses, and the stator is air-blast cleaned. The polished surface of the stator is then degreased with a cloth dipped in gasoline, and dried in air until the smell of gasoline has completely vanished. The polished surface of the degreased and dried stator packs are painted with a thin film of varnish applied with a brush. At the same time, the recesses and wedges are painted too. The paint used is No. 1154 glyptal varnish which has a specific weight of 0.875 and a viscosity of 3-4 sec, according to the NIILK funnel, or 13-15 sec according to the GIPI-4 funnel.

The painted stators are dried first for 30 min in air, and then for 3-4 hours in a drying chamber at 100-110°C. After this the stators are taken out of the chamber and allowed to cool down. Before the second painting the stators are wiped with a cloth dipped into gasoline, and after the gasoline has evaporated the polished surface and the recesses of the stator are again brushed with varnish of the same consistency as that of the first coat. Then the stators are dried, first for 30 min in air at a temperature of 16-25°C, and then in a drying chamber at 100-110°C, for 6 hours. The dry stators are taken out of the chamber, cooled in air, and their electrical parameters and outer shape are inspected. The thickness of the coating must be 0.01-0.025 mm, the film must be yellow, tough, shiny, and without stains. The stator packs may be varnished also with a paint sprayer.

Painting of the Rotors

Rotors of gyromotors made of steel and having no metal plating are spray-coated on their outside, which gives them a thin and uniform film of varnish. The inner surface of the iron pack of the shunt-wound rotor is coated with a film of varnish by means of a brush. Paint spraying must be done in a clean, bright, separate room with good ven-

tilation by means of a special installation.

The device for paint spraying consists of a paint sprayer — an atomizer connected by a rubber tube to an oil-water separator, and the paint supply tank. The oil-water separator is connected by an air pipe to a factory compressor or to a special compressor, cleans the pressurized air of moisture and oil vapor, and controls the air supply to the paint sprayer and paint supply tank.

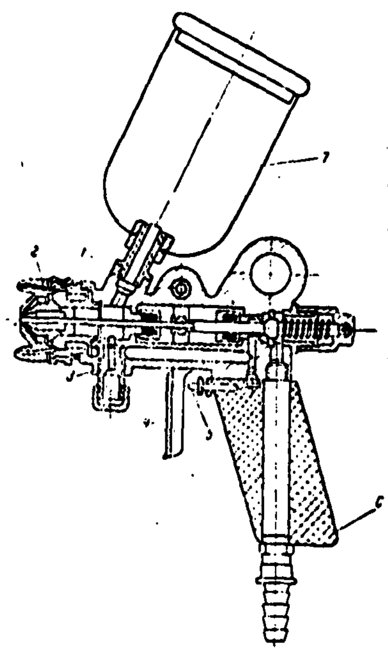


Fig. 78. Paint sprayer. 1) Body; 2) atomizer; 3) adapter with nipple for paint; 4) trigger; 5) setscrew; 6) handle with nipple for air.

The paint supply tank serves to feed the paint into the sprayer at a constant pressure.

The varnish is atomized in the sprayer because varnish and compressed air are supplied from two channels in the jet of the atomizer. At the mouth of the jet the varnish is carried along by the pressurized air and settles on the part in the form of dust. The varnish is supplied through a tube from the oil-water separator, or flows out from a container fastened to the sprayer, as in the case of the KR-2 paint sprayer (Fig. 78).

The paint is applied in a special spray chamber which is designed for collecting and removing from the work all the varnish fog arising during spray varnishing and consisting of fine particles of varnish and the vapor of its solvent.

The spray chamber with the fog collector (Fig. 79) consists of the working space 1 in which the item to be painted is placed; the water filter 2 which cleans the air contaminated with fog; water atom-

izers; a water circulation system with a pump; the ventilation unit 3 including a zigzag-plate separator for separating the moisture particles from the air in the case of water cleaning; a fan with electromotor drive, and an air drawoff.

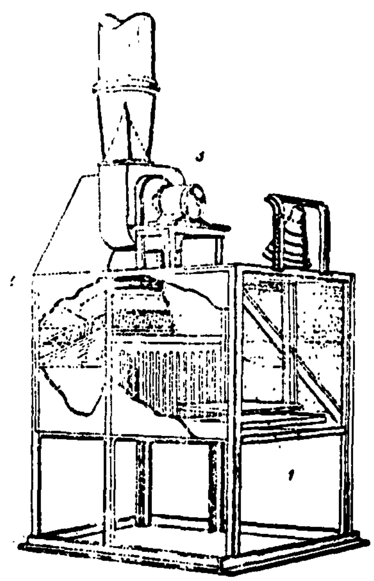


Fig. 79. Blind pass paint spraying chamber with fog collection.

In the room where the spray chambers are installed together with their water cleaning, the remaining air, the chamber, and the drawoffs are not choked with varnish. The danger of the varnish catching fire in the room is thus reduced to a minimum.

The rotors, just like the polished surface of the stators, are coated with No. 1154 (kiln-drying) glyptal oil varnish. The viscosity of the varnish before the coating of the rotors must be 3-4 sec according to the NIILK standard funnel, or 13-15 sec according to the GIPI-4 funnel. The required viscosity of the varnish is reached by diluting it with a solvent consisting of 50% turpentine and 50% white spirit. When the varnish has been diluted to the required viscosity, it is cleaned of impurities by filtering through a metal sieve with 3200 holes per square centimeter, or through several layers of cotton gauze and led into the tank of the paint supply pump or into the container of the paint sprayer.

Finally, after the treatment the rotor, whose necks have not yet been ground, is carefully cleaned of dirt, dust, and projecting parts on the outside and inside. The painted surfaces must be free from traces of corrosion.

Before the rotor surface is painted, it is degreased by putting it completely or half-way into a gasoline bath and washing the surface that is to be painted. The recesses of the iron are cleaned of dirt with a thin nonmetal plate wrapped into a batiste cloth, and then washed with gasoline so that no oil remaining from the preservation or other impurities are left on the rotor surface.

The rotor, which has been degreased and washed, is taken out of the bath, and special caps are screwed on the threaded parts of its axle. In all the following operations these caps are used for handling the rotor, which keeps its surface from being soiled. After the inner surfaces of the rotor have been cleaned the latter is put into the gasoline bath once again together with the caps. It is dipped in several times. The gasoline residues are shaken off from the rotor, and its surface is wiped dry with a batiste cloth. The rotors washed in this way are placed in a special glass chamber on a support and air-dried for 1-1.5 hours at a temperature of $20 \pm 5^{\circ}C$ until the gasoline has vanished completely. Thereafter, the rotors are put on special metal stands in the drying chamber and are dried for 2 hours at a temperature of $200 \pm 20^{\circ}C$ until the grease which has fallen between the iron plates and into thegap between rotor and pack during the time of preservation has vanished or become completely solid.

Incomplete removal of grease from the inner surfaces of the rotor or its solidification can lead to flaws in the gyromotors when their rotors are balanced.

In one of the factories the author had to demonstrate why a large batch of gyromotors in which the rotors had been balanced according to the technical specifications and inspected by the checker had to be rejected because of imbalance. After this, the gyromotors were assembled. The gyromotors were also balanced and put through a six-hour

preliminary and a three-hour routine test run. The imbalance found proved to be within the limits of the standard. However, in tests for checking the quality of balancing after an 18-20-hour cooling of the gyromotors (in a room having a temperature of 15-18°) nearly 60% of the first batch checked were rejected because of imbalance of the rotors. In the following batches too, some of the gyromotors were rejected owing to their increased imbalance.

When the reason was sought it was found that the rotors were unbalanced within the limits of the corresponding tolerances before assembly. During the checking of the balance after assembly and after the three-hour routine test run, the assembled gyromotors were also packed away as satisfying the tolerance of imbalance. When cooled down for one day at normal temperature they proved to be unsuitable owing to imbalance. In this way it was found that gyromotors in a cold state do not satisfy the technical specifications (TU). As the rotors taken out separately from the rejected gyromotors were heated, the grease used to preserve the steel parts ran out of the clearances between the iron pack and the flywheel in the rotor and from the gaps between the individual rotor plates. When these rotors were cooled down the grease became solid again and gathered on the lower parts of the gyromotor. Thus it was established that the reason for the rejection of the gyromotors of the given batches was the presence of anticorrosion grease used to preserve the rotor packs after grinding between the individual rotor plates. As the rotors were balanced in the frame (during this procedure the rotors are cold), this grease remained in one place; during operation the assembled gyromotors became warm, and the grease turned liquid and took another position. After the gyromotors were disconnected from the feed circuit they cooled off, the grease ran to the lowest part of the rotor iron pack lying horizontally and solidi-

fied, thus causing the imbalance of the rotor during the test and consequently the rejection of the assembled gyromotors. The rejected gyromotors were dismantled, and their rotors were again balanced after a long period of drying in a thermostat at a temperature of 200°C until the residues of the grease were completely removed and hardened. Gyromotors assembled with these rotors no longer showed any rotor imbalance.

The hazard of the type of flaw described above is also the reason why the rotors are dried at such high temperatures and for such a long time before they are painted.

Before the rotor surface is painted it is rubbed once more with a batiste cloth slightly moistened in acetone or gasoline and dried in air until the smell of gasoline or acetone has vanished; only then are the inner surfaces of the rotor behind the shunted winding painted with a brush with No. 1154 varnish of the same concentration as that used for the stators. The areas to be painted are then wiped again with a dry cloth, and the outer surface is spray-painted first, and then the inner surface and the shunted winding. For this purpose the rotor is held and turned on a rack. The painted rotors are placed in a glass chamber at normal temperature and dried for 0.5-1 hours. Then they are transferred to the drying chamber and dried at a temperature of 100-200°C for 3-4 hours.

After drying, a special spiral is traced on the rear surface of the rotor, serving to determine the number of rpm of the assembled gyromotor. The quality of the coating is inspected, and there must be no pits or large dust particles which have adhered to the varnish film in the process of painting and drying.

In some factories, a band 3-5 mm wide is painted on a length equal to half the diameter of the rotor instead of the spiral, and

circular points are marked with brightly colored PN-35-99 varnish at angles of 90°. After the spiral has been applied, the rotors are degreased with a cloth soaked in gasoline and are then dried in a glass chamber at normal temperature until the smell of gasoline has vanished. The dry rotors are once again painted in the spray chamber with No. 1154 varnish of the same viscosity. The outer surface is painted first, and then the inner surface; the rotor is held and turned in a rack so that the varnish is applied uniformly over the entire surface and the thickness of the coating lies between 5 and 25 μ. After the rotors have been painted for the second time, they are dried in a glass chamber for 1-1.5 hours at normal temperature and then in a drying cabinet for 4 hours at a temperature of 100-120°C. After this, the temperature is raised to 200-210°C and drying is continued for 2 hours.

The rotors which have been painted and dried must be golden in color. The film of varnish must be glossy, smooth, free from wrinkles, clearly visible beads and streaks of varnish, must not scale or peel from the surface of the rotor, and must not exhibit fingerprints or unpainted spots. There must be no traces of corrosion under the varnish film. The varnish film must not smear when the painted and dried rotor surface is wetted with acetone. The thickness of the coating (5-25 μ) is determined by measurements at certain points on rotors selected for spot-checks before and after application.

The gyromotor rotors painted with No. 1154 varnish by this technique produced good results during operation under stringent atmospheric conditions.

BF-4 adhesive is sometimes used instead of varnishes and paints. It gives the surface of the part highly anticorrosive properties, resistance to moisture, and mechanical strength, when applied without an undercoat, which differentiates in favor of painting with this adhe-

sive compared with other methods of anticorrosive coating. The technique of painting with colored BF-4 adhesive is as follows: the first coat is applied without any pigment in the adhesive and is dried in air for 30 min; the second coat consists of adhesive to which nigrosine or some other pigment has been added to produce a black coloration. This coat is dried in air for 30 minutes and then in a kiln at a temperature of 80-90°C for 2 hours. The third coat, adhesive containing nigrosine, is applied similarly to the second, and kiln-drying is extended to 5 hours.

Two bands 2 mm wide are painted with NP-35-99 varnish at an angle of 90° on the outer surfaces of the painted rotors destined for balancing machines.

§46. MEASURES TO PREVENT CORROSION OF GYROMOTORS DURING MANUFACTURE

The gyromotor parts, and particularly those made of steel, are subject to corrosion during manufacture, owing to the presence of reactive agents in the surrounding medium, especially to that of moisture with oxygen and other gases dissolved in it. These reactive agents interact with the surface of the part to be worked, corroding the surface and penetrating into the metal.

The appearance and development on the surface of steel parts of gyromotors during manufacture are favored by the following: moist air in the workshop and intermediate storerooms, contamination of the workplaces, the workers having dirty and perspiring hands, insufficient cleaning and finishing of the surfaces of the part and tool, shortcomings of the flushing and greasing materials.

Measures must be taken to prevent corrosion of gyromotor parts during manufacture, during storage between manufacturing operations and during their performance in instruments. The surfaces of parts attacked by corrosion during manufacture can only be subsequently freed

from it with great difficulty; it is therefore important to observe the instructions for the prevention of corrosion while the parts are being manufactured. The operations in manufacturing steel parts for gyromotors, particularly the final operations, must be performed in rooms where the relative humidity of the air does not exceed 50-60%.

To develop measures for the prevention of corrosion the technical process of manufacturing gyromotor parts, especially steel parts, is analyzed, the operations that are most liable to produce corrosion are spotted, and the possible times for which parts can be stored during the individual operations and between them are determined.

Certain anticorrosive lubricants and methods of preservation exist for protecting gyromotor parts from corrosion during manufacture and storage.

Greasing with vaseline, which is a mixture of solid and liquid hydrocarbons, appears to be the simplest and most widely used method of short-time preservation and long-term protection against corrosion. It was shown in special investigations that at a thickness of 20 μ this medium provides complete protection against moisture. The investigations also showed that a layer of ordinary grease 50-100 μ thick completely protects the coated metal surface from diffusional penetration of moisture and therefore also against corrosion.

When steel parts are to be preserved, it is necessary to keep in mind that the layer of grease does not protect the surface against corrosion and that in turn the corrosion will spread considerably under the layer of grease unless the surface is properly prepared and there are no fingerprints or other contaminations. The surfaces to be protected must therefore be carefully cleaned and degreased.

The anticorrosive coating of steel parts with vaseline during manufacture and storage is carried out as follows:

Traces of contamination are removed from the mechanically finished gyromotor parts with a cloth slightly moistened with gasoline, which must be free from traces of contamination when cleaning is complete. The surfaces of the parts are then degreased with first-class gasoline. Degreasing is carried out by immersing the surfaces in a gasoline bath and then drying the part in air until the smell of gasoline has vanished completely.

The parts which have been degreased and dried, or their surfaces that have to be protected, are covered with a layer of vaseline by means of a gauze pad. The part may also be coated by dipping it into a tank containing vaseline heated to a temperature of 100-120°C. The vaseline layer must cover the surfaces of the parts uniformly, without any gaps. There must be no traces of corrosion, contamination of fingerprints under the vaseline layer.

The stator packs which have been mechanically finished are cleaned with a cloth dipped in gasoline, put in the drying chamber, and dried for 5 hours at a temperature of 120-140°C; after this, they are taken out, cooled down to the temperature of the surrounding air, and degreased by immersion in a gasoline bath, or rubbing them with a cloth dipped in gasoline. The degreased stator and rotor packs are coated with a thin film of vaseline by means of a pad or brush, wrapped in tissue paper and stored in temporary store-rooms. The preserved parts are inspected periodically and are protected again if corrosion is detected on the surface under the grease. Not more than 4 hours are allowed to elapse between the operations of mechanical working and protection by means of vaseline. Preservation with TsIATIM-202 grease (TU [Technical Specifications] 517-54) produces better results than preservation with vaseline.

To protect steel gyromotor parts during manufacture and storage

between production processes, the technique of preservation with sodium nitrite is sometimes used; this is less expensive, less complicated and gives satisfactory results. This preservation consists in immersing the clean machined parts in a bath containing sodium nitrite at a concentration of 5-10% at normal temperature for up to 5 minutes between operations. When the surfaces of the steel parts are in contact with the solution, a protective layer will arise which can be removed by washing the parts in aqueous solutions (emulsion, solutions of soda and soap). The layer is insoluble in gasoline and turpentine, which is very important in the production of gyromotors since their parts are washed in gasoline. Rectified spirit is also incapable of dissolving the layer at an appreciable rate.

Gyromotor parts are successfully protected against corrosion when they are stored in desiccators containing special dehydrating agents. Between the mechanical operations of machining, finishing and assembly, the parts are stored in a glass desiccator, with a blue silica gel indicator dried at a temperature of 120°C for 2 hours on its bottom. The silica gel under the glass dome absorbs the moisture which would corrode the parts; as absorption proceeds, the silica gel changes in color, turning from blue to pink. To restore the moisture-absorbing properties of the silica gel, the latter is dried for 2 hours in the drying chamber at a temperature of 120°C.

To reduce the corrosion of the parts, the workers must wash their hands at regular intervals in a 2% formalin solution.

Manuscript Page No.	[List of Transliterated Symbols]
198	ГИПИ = GIPI = Gosudarstvennyy nauchno-issledovatel'skiy i proyektnyy institut = State Design and Planning Scientific Research Institute.

207 ЦИАТИМ = TsIATIM = Tsentral'nyy nauchno-issledovatel'skiy institut aviatsionnykh topliv i masel = Central Scientific Research Institute for Aviation Fuels and Oils

207 ТУ = TU = tekhnicheskiye usloviya = technical specifications

Chapter 5

ASSEMBLY OF BALL BEARINGS AND BALANCING OF THE ROTOR

§47. FUNDAMENTAL ASPECTS

Modern gyromotors work with high rotation speeds of the rotor. Centrifugal forces of inertia, which arise because of imbalance of the rotor belong to the basic sources for the generation of vibrations of gyroscopic devices and lead to a progressive wearing of ball bearings, even to destruction.

The dynamic balancing of gyromotor rotors can be carried out at operating rpm and at lowered resonance rpm. Balancing at operating rpm in the case of great imbalance and high operating rpm may cause deterioration of the quality of the working surface of the ball bearings. Investigations demonstrated that the balancing of rotors of high-speed gyromotors should be divided into two operations: a preliminary one at resonance rpm, or rpm 0.2-0.1 times smaller than operating rpm and a final one at operating rpm. Such separated balancing secures the necessary accuracy and does not decrease the quality of the ball bearings during balancing.

The accuracy of dynamic balancing depends not only upon the accuracy of the equipment and the proficiency of the operator, but also on the quality of the bearings of the gyromotor and, especially, on the precision shaping of the necks, the assembly, and quality of ball bearings.

§48. PACKING AND PREPARATION OF BALL BEARINGS FOR ASSEMBLY

Marks are applied with a stamp in manufacture of ball bearings on

faces of outer and inner rings. The serial number of ball bearings is applied by a chemical method (with subsequent neutralization) to the outer cylindrical surface of outer rings. The serial numbers should not be repeated during the same year.

The components of ball bearings are not interchangeable, since the dimensions of ring and balls are selected in assembling ball bearings to correspond to blueprints and the technical specifications of clearances. Each radial-thrust ball bearing is therefore fastened with a clamp of spring carbon steel, or tied with copper wire.

The assembled ball bearings are inserted into glass test tubes after washing and lubrication and covered with liquid industrial oil. To each test tube containing a bearing is glued a wrapper on which the factory indicates its number and also the number of the ball bearings. For each consignment of ball bearings, the manufacturer issues a quality chart, as well as a rating plate indicating the serial numbers, the actual mean arithmetical dimensions of seating places for each ball bearing and the serial number of the test tube in which it is packed.

The boxes with ball bearings can be stored in the storeroom unopened for a maximum of one month. The boxes have to be placed on wooden floorings at a height from the floor of not less than 0.2 m and a distance from the outer wall of at least 0.75 m. After opening these boxes, cardboard boxes containing the ball bearings are taken out and stored on special shelvings or sent for assembly. When boxes with ball bearings are received in the cold season the boxes should not be opened before 24 hours or later than three days.

The temperature should lie between +10 and +30°C, and the relative humidity of the air should not exceed 70% in the storeroom for the ball bearings. The preparation of the preserved ball bearings for

storage must be carried out in a special compartment with good ventilation and the necessary fire-fighting devices. The cardboard boxes are unpacked in these compartments, the test tubes containing the ball bearings covered with special oil taken out and dust is wiped off with a clean cotton fabric. The oil is cleaned off from the stopper of the test tube, the tube opened and the oil poured into a large glass bottle. The ball bearings are withdrawn from the test tubes with a hook or pincers and transferred to a perforated box. These boxes are made from an iron sieve which is drawn on a frame of iron wire. The box has an iron handle by which it is held by hand during washing and hung up on special crossbeams of the wash bath.

The ball bearings, inserted into the perforated boxes, are immersed in the tank filled with "galosha" or "B-70" gasoline. The washing is carried out in two tanks by immersing the box 5 or 6 times in gasoline. The gasoline in the tanks must be pure, filtered through filter paper.

In some foreign firms, particularly the firm "Sperry," the washing and degreasing of ball bearings is carried out in a stream of gasoline or emulsion. After washing and degreasing, the ball bearings are stored in boxes inserted in a chamber. Filtered lubricant is supplied under pressure into the chamber, so sprayed that each ball bearing is covered all around with a layer of lubricant of the necessary thickness. The lubricated ball bearings are taken from the chamber, wrapped in lint-free paper or stacked in a desiccator for the necessary time. The desiccator contains a screen insert with blue or blue-green silica gel indicator. According to the requirement the ball bearings are transferred from the desiccator to a test or to the operation of balancing the rotor.

To avoid corrosion the ball bearings have to be handled with rub-

ber gloves, pincers or lint-free paper.

A second preserving operation is carried out with ball bearings stored more than one year in delivery state. The oil is poured out from the test tubes, the ball bearings withdrawn with hooks and the remaining lubricant removed by washing in perforated boxes in gasoline baths as described above. After removing the lubricant and drying off the gasoline, the ball bearings are again put into the same thoroughly washed and dried test tubes and covered with fresh liquid oil. The stoppers of the test tubes are covered with paraffin, wax, or cellulose nitrate varnish and again placed in the cardboard boxes, where the ball bearings can be stored for one year.

§49. CHECKING THE BALL BEARINGS

As was said above, the ball bearings of gyromotors work under severe conditions and upon their work depends the precision of indication of the apparatus and longevity during the guarantee period. The ball bearings ensure free revolution of the rotor, which has to be smooth at high speeds, without vibrations and noise.

To ensure the normal operation of gyromotors it is necessary that the basic parameters of the ball bearings are in agreement with the norms for the given type.

Frictional Moments in Ball Bearings

Several instruments of various constructions exist for determining frictional moments in ball bearings under static conditions.

The frictional moment in radial-thrust ball bearings is determined in assembling gyromotors, both by determinations on apparatus and by the ease of motion and duration of revolution of the outer ring. In this case the inner ring of the ball bearing is put on a tapered brass mandrel and the outer ring of the ball bearing set in motion with the finger. The revolution speed of the outer ring decreases

quickly or the ring stops suddenly in the presence of an increased frictional moment or any other defect. Such a ball bearing is rejected. Besides testing of single ball bearings the frictional moment is also tested after assembling the ball bearing with the rotor pin. To do this, the outer ring of the ball bearing is put on the neck of the axle and tightened with the fingers, or is placed in the seat of the cover of the gyromotor. The rotor is then set in motion by hand, and the revolution and stopping are checked. In case of good fits on the neck and normal frictional moment in the ball bearing the rotor stops smoothly after revolving for a relatively long time. If the rotor stops quickly the ball bearings have to be removed from the neck and the frictional moment in it has to be examined.

Measurement of the Magnetizability of Ball Bearing Parts

One of the basic characteristics of gyroscopic ball bearings is their magnetic condition. Parts of ball bearings have to be demagnetized since magnetization of the outer and inner ring, as well as of the balls promotes the accumulation of metallic dust in the ball bearings. The metallic dust falls during the revolution of the ball bearings on the races of the rings under the balls, disturbing first the balance of the rotor and afterwards destroying the rolling surface of the rings.

The magnetization of steel parts of ball bearings may occur during the assembling of the gyromotors, in presence of magnetic fields in the rooms of the assembly section and at the working places.

There exist instruments for testing the magnetizability of steel parts of ball bearings based upon the measurements of the residual magnetism in the ball bearing or its parts. Figure 80 is a diagram of such an instrument of the type Ch-004 for measuring rings of ball bearings of all types and weights from 0.5 to 1500 g and inner diame-

ters from 4 to 150 mm.

The Ch-004 magnetometer is designed to measure the residual magnetism in assembled ball bearings and their steel parts. This instrument operates on the principle of a high-frequency measuring generator.

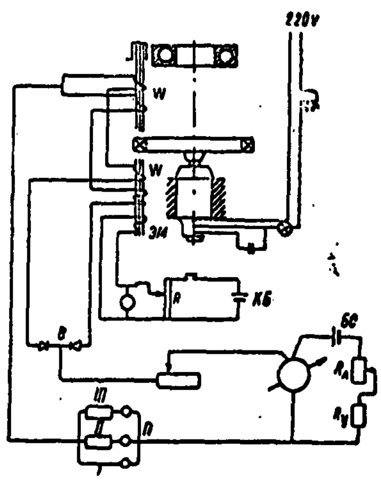


Fig. 80. Diagram of the instrument for testing magnetization of ball bearings and their parts.

The generator is excited by the magnetic flux of the ring or the assembled ball bearings installed on the plate of the instrument. Permalloy packs, fitted in a disk driven by an electric motor, rotate continuously and steadily between the poles of the coils W, which have permalloy cores; the voltage to be measured is generated on the terminals of the coils W.

While the disk revolves continuously, the permeance of the air gap between the packs changes periodically; this sets up an electromotive force in the windings of the coils W which is proportional to the residual magnetism of the piece. The emf of the 1500 cps AC generated is rectified by the two rectifiers B and then fed to the terminals of the reading galvanometer G.

Thus, the galvanometer readings depend on the magnitude of the residual magnetism tested and on its polarity. Rings and ball bearings of equal residual magnetism (magnetic induction) but different weight have different magnetic fluxes, and hence the sensitivity of the instrument is inversely proportional to the weight of the piece tested. The sensitivity of the instrument can be altered by means of the commutator P, which has three switch positions (I, II, III).

When switching from one measuring range to another, the position of the galvanometer needle must be corrected accordingly. A correction circuit exists for this purpose, consisting of the element BS and a rheostat, the 0.5-megohm resistance R_x, and the 1000-ohm limiting resistance R_y.

The accuracy of the indications of the instrument is checked with the control block KB, which is a standard electromagnet built into the instrument. The rheostat R is used to carry out the check: the button K is pushed, the allowed current size in the standard electromagnet EM is adjusted with reference to the voltmeter V, and the instrument readings thus obtained are compared with those required by specifications.

The magnetizability of steel ball bearing parts can also be checked by more simple methods. One of these proceeds as follows: the part or ball bearing to be tested is hung from a length of pack thread 300 mm long between the poles of an electromagnet, such that it is 20 mm from one pole and 30 mm from the other. The object tested is suitable if it is not attracted to one pole of the electromagnet when the field strength between the poles is 1000 oersteds. Displacement of the object with reference to the vertical when the current is switched on or off is not a reason for rejecting it.

The Determination of the Radial Clearance

For ball bearing regular servicing it is necessary to determine the radial clearance. The recommended minimum radial clearance for gyromotor ball bearings is 0.004 mm, which takes account of temperature variations during operation.

During operation the rings of the ball bearings are heated by the friction of the balls on the rings (usually the inner ring is heated more than the outer one). Experience shows that the temperature dif-

ference between the rings in radial ball bearings is not greater than 10°C. The temperature nonuniformity of the rings changes the radial clearance of a ball bearing, and the resulting decrease can be described by

$$\Delta_б = \alpha \Delta t 2r,$$

where Δ_b is the amount of diameter change of the track of the outer ring; α is the coefficient of linear expansion of the material (steel: $11.7 \cdot 10^{-6}$); Δt is the temperature difference between the ball bearing rings in degrees centigrade; r is the radius of the track of the inner ring.

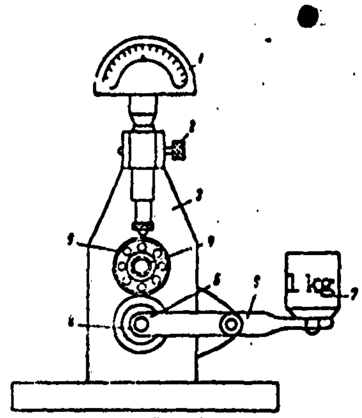


Fig. 81. Instrument for determining radial clearance in ball bearings.

The radial clearance of assembled ball bearings can be determined by instruments of different types. The principle of these instruments is to fasten the inner ring to a fixed bolt with a sliding fit. A weight is pressed in radially on one side of the outer ring, and on the other side of the ring a counterweight is installed which is usually the feeler of an indicator or another exact measuring instrument.

One such device is shown in Fig. 81. The ball bearing 9 to be tested is fixed on a bolt 4 on the body 3 by its inner ring. The screw 2 fastens a micron indicator 1 to the upper part of the device; its feeler is adjusted to the outer ballbearing ring. In the lower part of the body, link 5 with weight 7 and roller 8 is mounted on arm 6 to touch the outer ring at the point opposite to the indicator feeler. The weight is such that the forces applied to the ring can set free the whole clearance. Before examination the ball bearings are lubricated by one drop of MVP oil applied to the track; the revolution of the outer ring around the fixed inner ring distributes the oil uni-

formly through the whole track. Thereafter the roller is pressed down, the indicator feeler is lifted and the ball bearing is fastened to the bolt; the feeler is let down, the indicator arrow is adjusted to zero or the indicator dial mark at which the arrow stands is noted. Thereafter the roller is pressed to the outer ring and the force produced causes a radial clearance above the balls. The difference of the indications before and after the roller is pressed to the ring is the radial clearance. Measurements are carried out at three points at least, and these are distributed uniformly over the outer ring surface, whereby the load acting from below at the moment of reading should be transferred through only one ball. The arithmetic mean taken from three readings is the radial clearance of the ball bearing.

The Determination of the Axial Clearance

In most gyromotors an axial clearance should exist or should be reduced to a minimum; in some gyromotors an axial clearance exists and it is necessary to know its size beforehand. If the axial clearance in a ball bearing is known, then it is possible to fix the elements of gyromotor construction which provide the necessary amount of it in the assembled instrument.

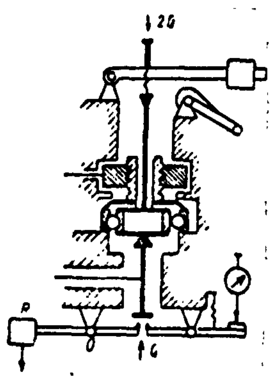


Fig. 82. Scheme of an instrument for axial clearance determination.

For measuring the axial and radial clearances there exist different types of instruments based on one and the same principle. The principle of measurement is that in the assembled ball bearing the inner ring is shifted axially relative to the outer ring which is fixed in position, or vice versa.

In Fig. 82 the scheme of the A-121 instrument designed to test the axial clearance of ball bearings with outer diameters from 9 to

35 mm is shown. When the axial clearance is measured the ball bearing is adjusted between two stages in such a way that the face of the outer ring is fastened by a pair of screws. The inner ring is displaced upwards and downwards during measurement by means of weights which produce a load on the ball bearing through a system of levers and rods. During measurement the ring is turned through a certain angle. The axial loads used in tests lie between 0.8 and 2 kg, depending on the size; indicators with a dial scale from 0.001 to 0.01 mm are used.

§50. MEASUREMENT OF THE VIBRATIONS OF A BALL BEARING

One of the most important factors determining the quality of ball bearings used in gyromotors are their vibrations at speeds near normal. From the magnitude of vibrations the quality can be determined, and the accuracy of the dimensions and shapes can be estimated together with the roughness. The balancing of rotors with ball bearings having small vibrations is carried out faster and more accurately. Gyromotors with such ball bearings work more smoothly and their lifetime is increased.

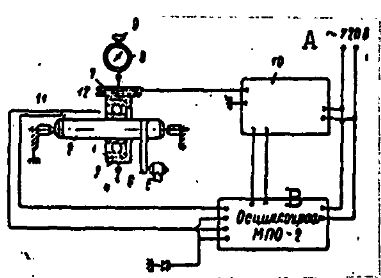


Fig. 83. Scheme of an apparatus for testing vibrations in ball bearings. A) 220 v AC; B) MPO-2 oscillograph.

Measuring ball-bearing vibrations requires a special apparatus permitting displacements to be read to within tenths of a micron.

A laboratory apparatus for measuring the vibrations in ball bearings is described below; it is used at the State Order of Lenin Ball Bearing Plant.

The scheme of the apparatus is shown in Fig. 83. The ball bearing 1 to be investigated is installed between the centers on a mandrel 2

with a radial beat in the range of 1 micron. A strap 3 is wound round the outer ring of the ball bearing so that it will fit in without any particular effort. The strap is prevented from rotating by a stopper 4 and is radially loaded by the constant force of a spring so as to

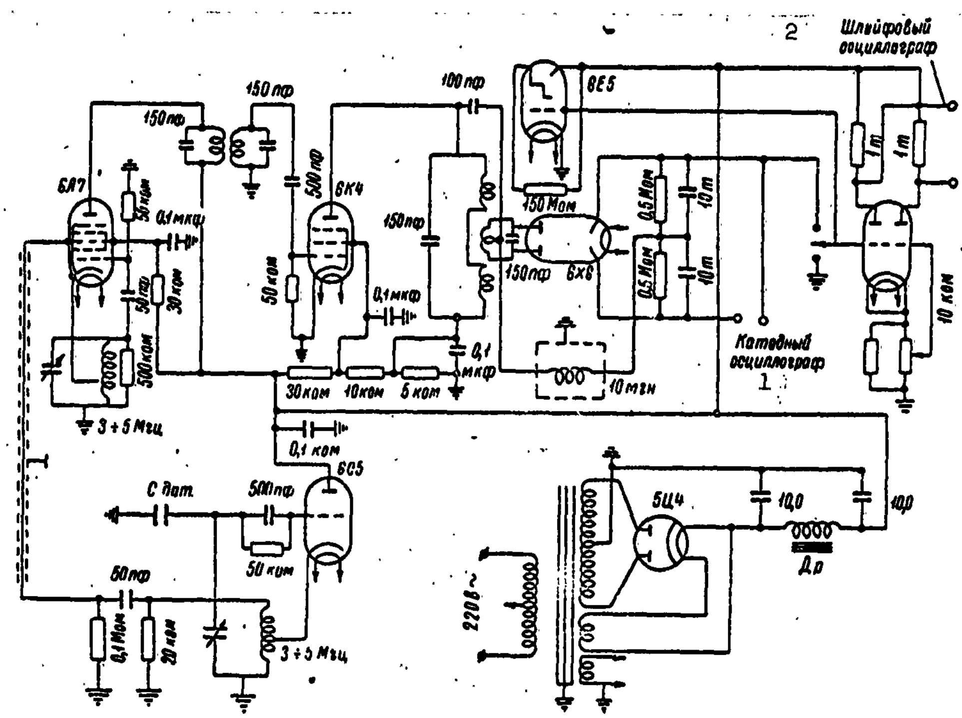


Fig. 84. Circuit diagram of the amplifier of the apparatus. 1) Cathode-ray oscillograph; 2) loop oscillograph.

eliminate clearance in the bearing during testing. The mandrel is driven at constant speed from an electric motor 5 by a belt drive 6. Since the inner ring is firmly fastened to the mandrel, the vibration produced in the elements of the bearing are transferred to the outer ring and to the strap. The capacitive transducer 7 has an upper and a lower plate. The lower one is connected firmly to the strap, the upper one is connected to the indicator 8 by a ball pivot. The ball pivot facilitates the parallel adjustment of the plates. By means of a screw 9 the feeler of the indicator can be displaced, together with

the upper plate of the transmitter, and the amount of displacement can be read on the indicator dial $\underline{x}$. To adjust the initial gap between the plates, a screw is used to bring the upper plate of the transmitter into contact with the lower one. Then the arrow of the indicator is set at zero, and after this the upper plate is lifted and the gap read from the dial. The area of the plates used in the apparatus is 9 cm^2, the multiplying factor of the indicator is 1 micron.

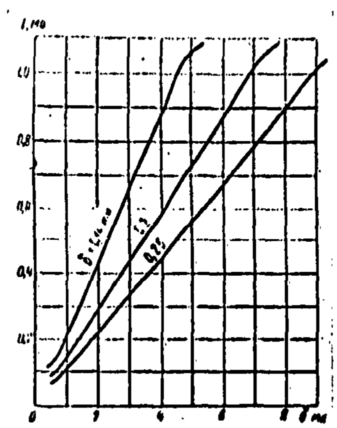


Fig. 85. Calibrating curves.

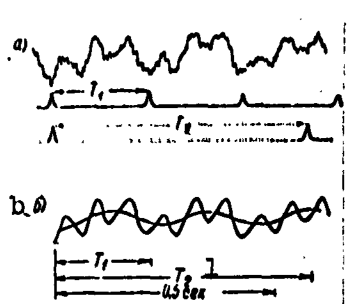


Fig. 86. Vibration recordings of a ball bearing. 1) Sec.

The capacitive transducer is connected to the input of an amplifier 10. The output signal of it is fed to a MPO-2 loop oscillograph which records the vibration process.

The time of one revolution of the mandrel and the separator is determined from the revolution markers 11 and 12 which are elastic contacts short-circuiting the mandrel and the separator at each revolution. The revolution marks are recorded on an oscillogram.

The main elements of the apparatus are the contactless capacitive transducer and the FM amplifier.

A schematic diagram of the amplifier is shown in Fig. 84. The 6S5 tube with the pickup connected in its grid circuit works as a generator. The 6L7 tube works as a generator too, and also separates the intermediate frequency which is amplified by the 6K4 tube. The 6Kh6 tubes are the main parts of the frequency detector. A low-frequency amplifier works with the 6N8 tube (triode on the left). The

6Ye5 indicator serves to tune the amplifier to the intermediate frequency in accordance with the shadow sector. The output power of the amplifier is about 2 watts.

In the pickup, gaps of 0.14, 0.2 and 0.25 mm are used, corresponding to capacities of 643, 450 and 360 picofarads. The sensitivity of the transmitter depends on the gap. The transmitter is calibrated by shifting the upper plate of the transmitter by a small amount and measuring the output current. A calibration diagram is shown in Fig. 85. It shows values for the sensitivity $K = \Delta J_{vykh}/\Delta_b$ of the amplifier (ΔJ_{vykh} is the amplifier output current variation in ma corresponding to a variation Δ_b of the gap in microns):

for $\delta = 0,14$ . . . . $K = 0,22$ ma/micron
" $\delta = 0,20$ . . . . $K = 0,14$ "
" $\delta = 0,25$ . . . . $K = 0,1$ "

The range of the measured amplitudes is characterized by the length of the straight part of the calibrating curve. The measurement error produced by a certain nonlinearity in the working part of the calibrating curve does not exceed 5% and is decreased if only a section of the working part is used instead of the whole. The apparatus can be used for all frequencies allowed for the MPO-2 oscillograph since the frequency ranges of the transmitter and the amplifier are both wide enough.

Figure 86a shows an oscillogram of the vibrations of a ball bearing with eight balls which was recorded with this apparatus. Figure 86b shows the same oscillogram after a treatment. The period of the first curve is the period of mandrel revolution (curve K_1) and that of the second (curve K_2) is considerably less. After one revolution of the separator eight cycles of the curve K_2 occur; the components K_1 are the beats of the inner ring taking account of the beats of the mandrel; the components of K_2 are the entries of each ball in the

loaded zone.

An investigation showed that the method suggested for determining the vibration of ball bearings may be used with success not only in ball bearing production plants but also in plants producing gyromotors.

§51. CHECKING THE BALL BEARINGS IN THE ASSEMBLED GYROMOTOR

The vibration testing of ball bearings described gives no objective evaluation of their quality in assembled gyromotors since small defects and incorrect assembling of one bearing affects the operation of the bearing working with it as a pair.

In order to ascertain the influence of one ball bearing upon the other at some of the plants the quality of ball bearings, and therefore their efficiency is evaluated by testing on assembled gyromotors at nominal speeds. It is assumed that this check only gives the main characteristics of ball bearings: friction moment, vibration, radial and axial beat etc. The working quality of a ball bearing depends directly on accurate assembling in the supports, on the accuracy of the dynamic balancing of the rotors, on the precision of assembly and subsequent adjustment of the axial clearances, and on the quality of the gyromotor assembly as a whole. This ball bearing test allows the quality of the main bearings to be evaluated since the quality of their work is a function of many factors. These may include the geometric accuracy of parts and units in the bearings, the accuracy of ball-bearing ring fitting and the dynamic balancing of the rotors.

Ball bearings in an assembled gyromotor are tested in electronic balancing machines with an oscillograph (Fig. 92). The machines consist of two independent supports with inductive pickups. These pickups are fastened on plate springs which are mounted on a movable frame. The emf induced in the pickups is amplified in an amplifier, then fil-

tered and fed to the electron-beam tube of an oscillograph in the form of a sine curve.

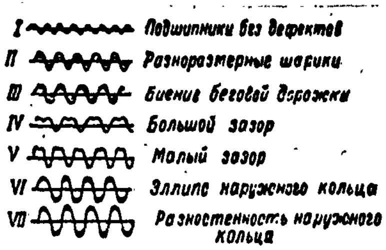


Fig. 87. Oscillograms characterizing the quality of ball bearings. I) Bearing without a defect; II) bearing with balls of different sizes; III) beat of the race; IV) too great clearance; V) too small clearance; VI) outer ring elliptic; VII) variation in wall thickness of the outer ring.

The quality of every ball bearing in a gyromotor can be determined individually by such an electronic machine; it is merely necessary to connect the corresponding pickups. In every ball bearing the main defects affecting accuracy and lifetime can be found, such as: different ball dimensions, beat of the races, enlarged clearance, ellipticity, and nonuniform dimensions of the revolving ring. The defects of the ball bearings in gyromotors are determined by comparing the curves obtained on the oscillograph screen with curves obtained in laboratory tests with predetermined ball bearing defects. Such curves are given in Fig. 87. As with the determination of the vibrations of single ball bearings, these curves consist of different components and are composed of harmonics.

Curve I is a sine curve and shows the absence of defects in the ball bearing.

Curve II consists of two sine curves having the same frequency but different amplitudes which shows that balls have different sizes.

Curve III is characterized by a beat of the ball race and consists of two sine curves shifted in phase by $T/8$ or $\pi/4$ and having different amplitudes.

Curve IV characterizes the existence of a large clearance and represents the general case of a periodic vibration, when the sine curve is the resultant of two harmonic curves with frequencies differ-

ing by a factor of two.

Curve V characterizes a small clearance and has a smaller period and a greater amplitude than curve IV. A study of the curve shows that small clearances produce vibrations with higher frequency and increased amplitude.

Curve VI characterizes the existence of an elliptical outer or inner ring and consists of two sine curves with coincident phases and equal periods but different amplitudes.

Curve VII is similar to curve VI but has greater amplitude which characterizes different wall thicknesses of the revolving outer or inner ring.

§52. THE NATURE AND THE IMPORTANCE OF BALANCING THE ROTOR

As mentioned above, regardless of the measures taken to ensure that the gyromotor rotors are accurately machined, a certain nonaxiality of the surfaces and nonuniform densities of bars and rings of the short-circuited winding are very important. When the rotor is mounted in the body and cover, nonaxiality of its surfaces is increased as a result of incorrect boring for the ball bearing and nonaxiality in body and cover, and as a result of nonaxiality of the inner ring and the bolt. All these errors produce unbalance of the gyromotor rotor during rotation.

To balance the rotor it is necessary that the center of gravity of it should lie on the axis of rotation and the centrifugal moments of inertia be zero, or, in other words, it is necessary that one of the central main axes of inertia should coincide with the axis of revolution. Noncoincidence of the center of gravity with the axis of revolution is called a static unbalance, and the centrifugal forces of inertia not being zero it is termed dynamic unbalance.

A dynamically balanced rotor is statically balanced too. There-

fore rotors of small-size gyromotors are dynamically balanced only. Rotors of gyromotors are dynamically balanced by hand or with balancing machines (a description of some of them is given below). In balancing by hand the relative amount of unbalance is determined by the worker from the amplitude of vibration of the supports of the rotating rotor by touch. The position of the unbalanced mass is found by shifting plasticine weights along the circumference of the rotor until the point is found at which vibration is a minimum.

20-30 starts are necessary to balance a rotor dynamically by hand. The rotor is started by pressing its surface against a rotating leather disk.

Dynamic balancing with balancing machines consists of determining the position and the amount of unbalance with a special device which measures the height and the phase of vibrations of the machine supports produced by the rotating rotor.

Direct balancing of the rotor is performed by hand in all cases and is carried out by boring metal out of the rotor or by welding material onto it. The accuracy of dynamic balancing depends on the quality of craftsmanship and which is what consumes the main part of the operation time. The accuracy of machine balancing is 5-15 mg-cm and the rate is one rotor in 10-25 minutes. It can be seen from the figures presented that the costs of dynamic balancing during gyromotor assembly are high.

§53. STATIC BALANCING

Static unbalance consists of noncoincidence of the center of gravity and the axis of revolution; the center of gravity is displaced from that axis by a certain distance. During rotation, a statically unbalanced part produces a centrifugal force. To eliminate this deficiency the part is statically balanced. The part is laid on exactly

horizontal prism edges; the sharp edges of the prisms ensure minimum friction in the supports during rolling. Figure 88 shows a device for static balancing. It consists of the plate 1, onto which the steel prisms 2 are fastened. The polished surfaces of the knives have to be exactly horizontal. The screws 3 allow the surfaces of the knives to be trued up horizontally.

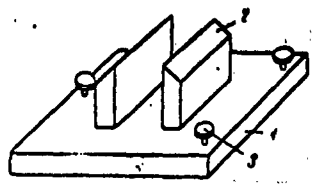


Fig. 88. Knives for static balancing.

The static balancing of gyromotors with this device is carried out in the following way: the assembled gyromotor is put on the prisms of the device with its journal and allowed to roll along the prism. If the gyromotor is not balanced and the center of gravity does not lie on the axis of revolution the gravity force produces a moment which tends to turn the gyromotor so that its center of gravity occupies the lowest position possible. After this the necessary weight and position is found for a counterweight such that the gyromotor does not show a tendency to rotate in any position. Plasticine is used for the experimental weights; little pieces of it are attached to the outer surface of the gyromotor temporarily. When the weights of the counterweights and their positions have been found, the plasticine is replaced by tin soldered to the gyromotor, or a part is cut away from one of the attached weights serving as a counterweight.

§54. DYNAMIC BALANCING

The dynamic balancing of cylindrical parts, such as gyromotor rotors, is based on a proposition established by Academician A. N. Krylov. This states that any desired rotor may be balanced by attaching (or removing) two masses located in arbitrarily selected planes perpendicular to the axis of revolution. All existing methods of balancing rotors make use of this proposition.

We consider the cylinder shown in Fig. 89a and b, which is divided into elementary disks. The individual disks are not balanced

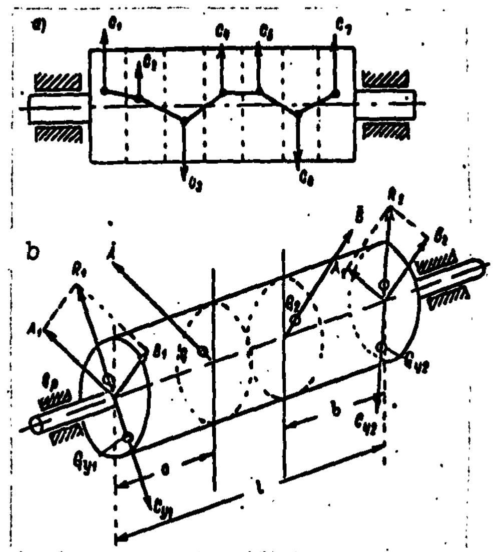


Fig. 89. Scheme of the conditions of dynamic equilibrium.

with respect to the axis of rotation of the whole cylinder; the resulting forces of inertia of the disks form a certain open polygon. During rotation of the cylinder the disks generate centrifugal forces C_1, C_2, C_3 owing to the forces of inertia, thus producing additional destructive forces in the ball bearings. It is necessary to ascertain the conditions under which the centrifugal forces of the disks are balanced and will not act on the ball bearings.

First, the problem is simplified by assuming that the cylinder is rigid, does not deform and has two unbalanced weights located at different distances from the ends, directed towards different sides and producing the centrifugal forces A and B during rotation.

These centrifugal forces may be resolved into two components as follows and transferred to the end planes of the cylinder:

$$A_1 = A\frac{l-a}{l}, \quad A_2 = A\frac{a}{l},$$

$$B_1 = B\frac{b}{l}, \quad B_2 = B\frac{l-b}{l},$$

where a is the distance from one end of the cylinder to the location of the vector of the centrifugal force A; b is the distance from the second end of the cylinder to the location of the vector of the centrifugal force B; and l is the distance between the ball bearings.

The directions of the vector components A_1 and A_2 and the vector components B_1 and B_2 are the same as those of the vectors A and B. Consequently, expanding the radial forces yields A_1 and B_1 in the first end plane and A_2 and B_2 in the second end plane. Geometrical addition of these forces yields two resultant forces R_1 and R_2 located in the two end planes, equal to the centrifugal forces $\bar{A}$ and $\bar{B}$ in magnitude and direction.

Therefore, if more than two unbalanced centrifugal forces are assumed then these forces can be resolved into components lying in the cylinder end planes, and all of them can be reduced to two equal unbalanced centrifugal forces applied to two arbitrary noncoincident planes perpendicular to the axis of revolution of the cylinder.

To achieve dynamic equilibrium it is necessary to apply balancing weights G_{u1} and G_{u2} to the diametrically opposed forces R_1 and R_2; the former exert centrifugal forces C_{u1} and C_{u2} equal in modulus and opposite in direction to the resultant forces R_1 and R_2.

The problem of dynamic balancing of cylindrical bodies is to find the size and location of the balancing weights whose attachment produces centrifugal forces equal and opposite to the unbalanced forces producing cylinder vibrations during rotation and destructive loads in the bearings. At equilibrium of these forces, the forced vibrations of the cylinder vanish.

In dynamic balancing the cylinder is balanced first at one end

and then at the other. The accuracy of dynamic balancing is substantially higher than that of static balancing.

For the exact determination of the size and location of the balancing weights in the dynamic balancing of gyromotor rotors there exist balancing machines of various constructions based on different principles of operation.

§55. METHODS OF DYNAMIC BALANCING

As shown above, a rotating cylinder can be balanced by two counterweights positioned in two different planes perpendicular to the axis of revolution. Selecting the position at which to apply the

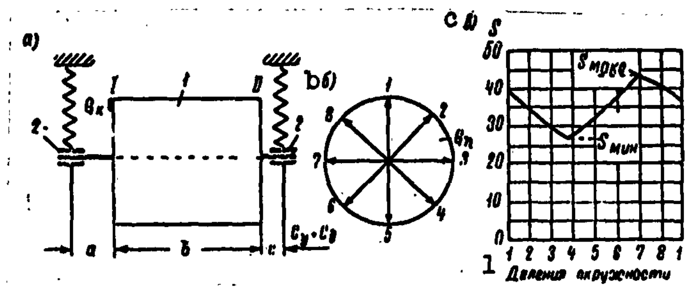


Fig. 90. Scheme of a device for dynamic balancing of rotors. 1) Indexing.

weights and determining the size of the balancing weight are the problems of dynamic balancing. All methods of dynamic balancing can be reduced to two main methods: the weight-circuit method and the maximum-mark method.

To give an explicit representation of dynamic rotor balancing one of the devices is considered.

Figure 90 shows schematically a rotor 1 to be balanced with one of its ends indexed into eight equal parts. The rotor is fastened in two elastic ball bearing supports 2, shown here as springs. During balancing, one of the bearings is fixed and the other one is allowed to swing in the vertical plane.

"Weight-Circuiting" Method

In the "weight-circuiting" method of balancing, the amplitude of vibration of the nonfixed ball bearing is measured and recorded at resonance revolutions of the rotor. After this a test weight is attached to every numbered section of one end in turn and the vibration amplitudes generated by this weight at resonance rotations are measured. The recordings are incorporated into a diagram (Fig. 89c); the abscissa shows the reciprocation of the rotor end and the ordinate the amplitude of vibration of the nonfixed bearing.

From the curve obtained the size and position of the balancing weight can be determined. Its weight can be determined from

$$G_у = 2G_п \frac{S}{S_{макс} - S_{мин}},$$

where G_p is the weight of the test weight; S is the amplitude of vibration without a test weight; S_{maks} is the maximum amplitude of vibration with a test weight; S_{min} is the minimum amplitude of vibration with a test weight.

If the results of balancing with a weight calculated from this formula and fastened at the lowest point of the curve are not satisfactory, the size and position of the weight at the rotor end should be changed. When the rotor has been balanced in one plane of the first bearing, this bearing is fixed and the second plane is balanced in a similar way. It is necessary to take account of the fact that the balancing weight G_u calculated for the first plane disturbs the balancing in the plane of the second bearing; to prevent such a disturbance a rectifying weight G_k is attached in the first plane of the first bearing. Its weight compensates possible disturbances of balance in theplane of the first bearing. The rectifying weight is attached diametrically opposite to the weight located in the plane of the first

bearing; its weight is given by:

$$\boxed{G_к = G_у \frac{c}{b+c}.}$$

In turn, the installation of a rectifying weight G_k disturbs balancing in the plane of the second bearing; therefore, to the balancing weight G_u in the plane of the second bearing an additional weight G_d has to be attached, determined by:

$$\boxed{G_д = G_к \frac{a}{b+a}.}$$

Here, c is the distance between the location of the balancing weight at the second bearing and the rotor end; a is the distance between the point of application of the balancing weight, measured from the first support to the end of the rotor; b is the rotor length.

Balancing by this method can be accelerated if the test weight is selected exactly. For vibration measurements at revolutions exceeding the resonance frequency, N.V. Kolesnikov suggested the following formula for calculating the test weight:

$$G_п = \frac{GS_p}{8R},$$

where G is the weight of the rotor; S_p are the amplitudes of rotor vibrations at revolutions exceeding the resonance frequency; R is the radius of test weight attachment.

The rotor speed is twice the resonance speed and the vibration amplitude of the free bearing is measured. At this speed of revolution the rotor vibrates about its center of gravity.

Consequently, the "weight-circuiting" method of balancing consists of two stages: determination of the balancing weight location and determination of the size of balancing weight.

The unbalance is determined by measuring the vibration amplitudes of a fixed bearing at resonance revolutions; first a constant test

balancing weight is shifted along the circumference of the rotor and then the weight of the balancing weight is varied at a given location. If location and amount of the balancing weight are properly selected the vibration amplitude of the fixed bearing is a minimum when the rotor is revolving at resonance.

Although this dynamic balancing method is difficult, it is more exact too, and it is based on measuring the maximum amplitude of ball bearing vibrations, a principle which is widely used in dynamic rotor balancing.

Balancing by the "Maximum Mark" Method

The "maximum mark" dynamic balancing method is based on the assumption that the amplitude of ball bearing vibrations is directly proportional to the centrifugal forces resulting from unbalance. Therefore, a variation of this amplitude is proportional to the sizes of the weights generating vibrations. Furthermore, it is assumed that the shift angles between the direction of maximum rotor rod excursion and the centrifugal forces producing it remains constant with different balancing weights under the same conditions.

With balancing by this method the cylindrical surface of the rotor or the surface of the shaft not covered by the ball bearing is coated with chalk or paint. As in the "weight-circuiting" procedure, one of the bearings is fixed and the other can vibrate in the vertical plane. The rotor is turned and at resonance revolutions, when the vibration amplitude of the free bearing is a maximum, single lines are plotted on the whitened surface by means of a scriber. The middle of the lines is the location of the maximum runout of the rotor at resonance vibrations. The mark of the middle of the lines is transferred to the rotor end; a second mark shifted 90° with respect to the first mark is then produced and a plasticine test weight applied to the bal-

ancing plane at the rotor surface at this point. The test weight is shifted with respect to the first mark because resonance vibrations have a 90° phase shift. After this the rotor is revolved at resonance speed and a new mark is taken; when the locations of the marks coincide the weight is correctly located but too small in size. The weight has to be increased until the colored surface shows no single points or the points are within tolerable limits. If one side of a rotor is balanced the second bearing is fixed firmly and the first bearing is set free; the second side of the rotor is balanced in the same way.

As in the "weight-circuiting" method of balancing, in balancing with the "maximum mark" method, rectifying and additional weights have to be attached to eliminate the influence of balancing weights on the other side of the rotor; the method is the same as discussed in the description of the first method.

As a result of support vibrations, the vibration amplitudes are not directly proportional to the weights producing them, and the angular shifts in the direction of maximum rod bending and the centrifugal forces producing it are not constant. Therefore, balancing with the "maximum mark" method sometimes gives unsatisfactory results.

§56. BALANCING MACHINES

Balancing machines used for balancing rotors can be divided into four groups according to their principles of operation: 1) the pendulum type; 2) the frame type; 3) the electronic type; 4) the vertical type.

For achieving accuracy and high efficiency, the machines of these types are differently designed and are supplied with special accessories for an exact determination of location and magnitude of the balancing weights.

A description of certain types of balancing machine constructions.

used in balancing the rotors of gyromotors in serial and mass production is given below.

§57. PENDULUM-TYPE MACHINES

Figure 91 shows the scheme of a pendulum machine intended for dynamic balancing of gyromotor rotors. The machine consists of a frame 1 hinge-mounted to move in one plane. The vertical position of the frame is fixed by two spiral springs 3. The lower frame end is connected to a mirror by means of arm 4 and rod 5. One revolution of the frame around its axis therefore produces a corresponding revolution of the mirror 8. If an unbalanced rotor is rotated, a torque about the axis is produced by the unbalanced centrifugal forces. This torque varies in magnitude and its direction with a period equal to the period of rotation of the rotor 2. Therefore, unbalanced centrifugal rotor forces make the frame swing and hence the mirror too.

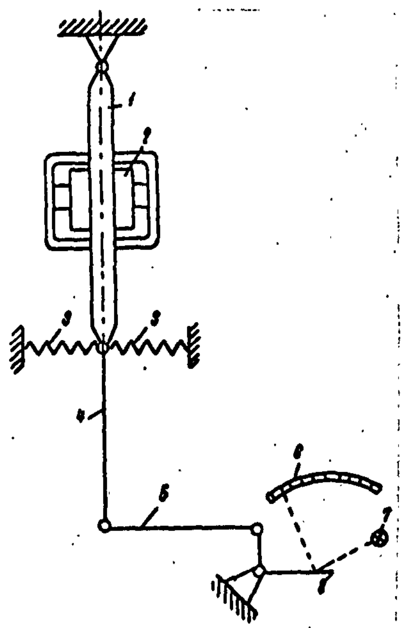


Fig. 91. Scheme of a pendulum-type machine.

The rotor to be balanced is mounted in the frame, which is fixed in vertical position by two springs. In this position unbalanced centrifugal forces act against the springs in both sides alternately. For great sensitivity the rotor is run at a speed which is equal to the corresponding resonance frequency; this produces a large frame vibration amplitude. Therefore the light ray coming from the lamp 7 and falling on the scale 6 undergoes great vibrations; the rotor unbalance is evaluated from the deviation of the light ray on the scale. If the rotor is unbalanced the light point in-

cident from the mirror on the matte glass scale is spread into a line. The shorter the line, the more exact the balancing. The balancing of rotors with pendulum-type machines is carried out in two planes with mounting of rectifying and additional weights as shown above. The magnitude of the weights and their location at the rotor end is determined by one of the methods described above.

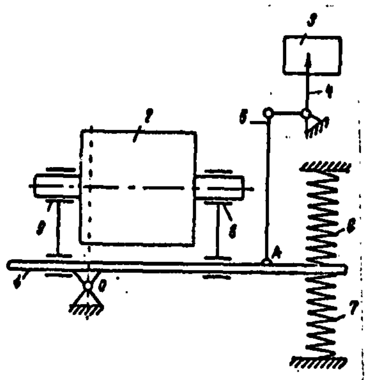


Fig. 92. Scheme of a pendulum-type machine with amplitude recording.

The mounting of the ball bearings on the journal axis, the assembly of the rotor with the frame and the removal of material from the rotor is carried out by the technological process described above.

Figure 92 shows a schematic diagram of a pendulum balancing machine with optical amplitude measuring.

The machine consists of the pendulum frame 1 the end of which is pressed between the springs 6 and 7; the frame is able to vibrate relative to the horizontal axis passing through 0. The supports 8 and 9 can be set up at the place on the pendulum frame 1 where the frame holding the rotor 2 to be balanced is installed (frames have been developed for every type of rotor). The amplitude of vibration of the unbalanced rotor is recorded on the smoked glass 3 by an arrow 4 which is connected to the pendulum frame rod 5. Balancing is carried out at revolutions corresponding to the resonance frequency by one of the methods described above.

There exist other balancing machines of the pendulum type, but in all these machines the results of balancing one side of a rotor influence the other side. This makes it necessary to calculate and attach rectifying and additional weights, thus complicating the balancing

process.

§58. FRAME-TYPE MACHINES

The feature of frame-type machines is that when one side of the rotor is being balanced the influence of the balancing weights on the other is excluded. Therefore the necessity of calculating additional and rectifying weights and mounting them disappears. This saves much time, especially in large series and mass production of gyromotors.

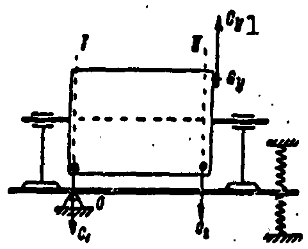


Fig. 93. Scheme of frame machine. 1) C_u.

Figure 93 shows a schematic diagram of a frame-type balancing machine. In this machine rotors are dynamically balanced in the following way: the rotor is mounted in the balancing frame in working ball bearings and then it is mounted in the frame of the machine which is free to swing about the axis O when the rotor runs. The machine frame is located in the balancing plane I. During rotation of the rotor the unbalanced centrifugal force C_1 which is located in the plane I passing through the machine axis produces no moment around the axis O; therefore it does not affect the vibrations of the frame. The forced vibration of the rotor with the machine frame is produced only by the action of the force C_2 which is located in the balancing plane II. It is obvious that a balancing weight G_u which eliminates the vibration compensates the unbalance in the given plane only. Therefore, when a rotor is balanced in the plane II the temporary action due to the rotor unbalance in plane I passing through O is eliminated.

When the rotor has been balanced in plane II, the frame with the rotor is turned around so that the balanced plane II passes through the machine axis O. The machine frame swings around this axis. Finally, the rotor is balanced analogously in the plane I. It is

therefore not necessary to mount rectifying and additional weights when balancing a rotor, and the process is greatly speeded up. However, in frame-type machines the weight of the machine frame vibrates with the rotor; this additional weight lowers the sensitivity of the machine and the accuracy of balancing. As a consequence the sensitivity and accuracy of frame-type machines are less than that of pendulum-type machines under the same conditions.

§59. MACHINES WITH OPTICAL AMPLITUDE MEASUREMENT

Frame-type balancing machines are used in series production of gyromotors to determine the unbalanced weight from the total amplitude

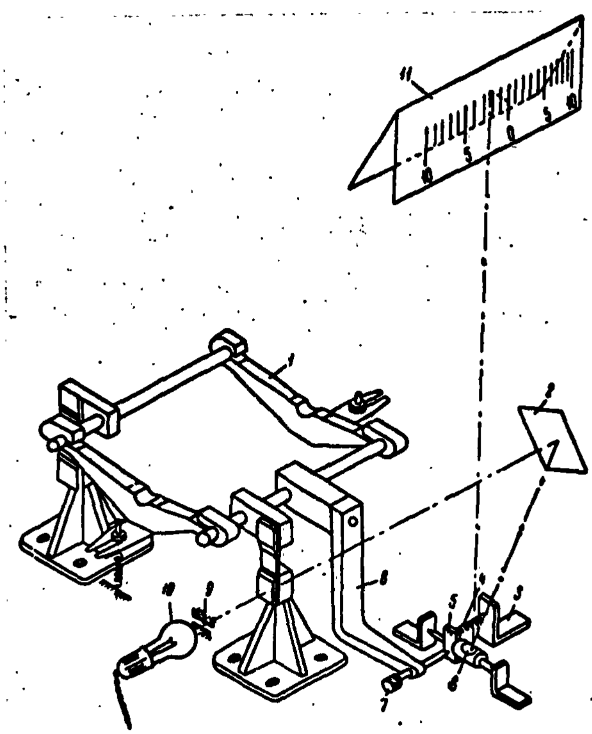


Fig. 94. Machine with optical amplitude measuring.

of resonance vibrations; these vibrations have to be determined with high accuracy. In this case optical amplitude measuring equipment is used (Fig. 94). In such machines the balancing of gyromotor rotors is

carried out in the following way: on the machine frame 1 the balancing frame holding the rotor is mounted on journals which have been previously mounted in ball bearings. After that, the rotor is assembled in the frame (a description of frame and assembly of the rotor is given in the consideration of balancing technology), the stator windings are connected to the machine terminals and the rotor is set into motion at a number of revolutions corresponding to resonance frequency; the vibration amplitude of the frame approaches a maximum in this case. The frame vibrations are transferred to the lever 8 into the end of which is threaded a regulating screw 7 resting on the lower half of plate 5. The upper half of the plate is pressed to the angle bracket 3 by means of a spiral spring 4. One axis of the plate has the mirror 6 fixed to it. The axis revolves in pointed journals which have a minimum clearance. The light ray coming from lamp 10 passes through the condenser and the slit 9, is reflected from mirror 2 and falls on the mirror 6 which swings around the axis and is reflected to the matte glass scale 11 of the machine which has a zero in the middle and uniform scale in both directions.

When the rotor revolves, its unbalance produces a vibration of the frame which increases considerably if the number of revolutions approaches the resonance frequency. The frame vibration produces a vibration of the lever which is transferred by the screw to the lower part of the plate; the latter is turned anticlockwise under the action of the screw beats and returned into the initial position by the action of the spring when the screw does not rock the plate.

If a balanced rotor is running the frame does not vibrate; the mirror 6 stands in its position and the light ray of the lamp is seen as a narrow light band on the scale. If the frame vibrates a wide band is seen on the scale instead of a narrow one. The width of this band

of light is equal to the total amplitude of the frame vibration magnified 50 to 100 times.

The total amplitude of frame vibrations is determined from the scale and hence the amount of weight necessary to balance the rotor in the balancing plane is found. A rotor which is balanced on one side is turned around in the frame, as described above, and its second side balanced.

Rotors can be balanced using balancing machines with optical amplitude measurement to a sufficient degree of accuracy. Machines with mechanical or electromechanical recording give worse results and are not considered in the present paper.

For determining the position of the unbalanced mass there exist devices based on mechanical, optical, electromagnetic and stroboscopic principles. We pause to consider two of them which are sufficiently exact and can be used in pendulum and frame-type machines.

§60. A RESONANCE-STROBOSCOPIC DEVICE

Figure 95 shows a scheme of a rotor balancing with the aid of a resonance-stroboscopic device. The rotor 2 to be balanced is installed on the frame 1 of the balancing machine; 1 is supported by the plate springs 5 and 8 whose other ends are fastened to the base 7. The rotor runs at a constant speed. The angular velocity of rotor revolution is greater by a factor of two than the natural vibrations of the rotor with the bearings; under action of the unbalanced centrifugal forces, the mass G vibrates with a frequency which is higher than the resonance frequency when the vibration has a phase shift of 180°. If the centrifugal forces produced by an unbalanced rotor are directed horizontally in one direction, the machine frame with the bearings deviates in the opposite direction. The maximum amplitude of frame vibrations is practically equal to the shift of the center of gravity.

On the machine frame a special indicator 4 is mounted vertically, consisting of a plate spring with a contact on the end and having a small mass. The natural vibrations of the indicator should be equal to

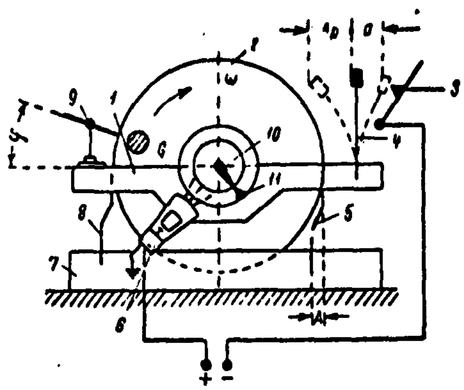


Fig. 95. Resonance-stroboscopic device for determining the location of weight.

the angular velocity of rotation of the rotor. Since the amplitude of indicator vibration at the resonance frequency in this case exceeds the amplitude of bearing vibrations, it may be determined from the formula

$$A_p = \beta_p A,$$

where β_p is the amplification factor, which is equal to $\beta_p = A/\varphi$ in the case of resonance, and φ is a quantity which is proportional to the resistance coefficient of the medium.

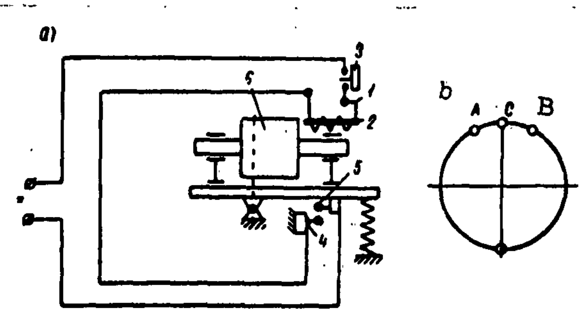


Fig. 96. Scheme of a machine with a phase searcher.

At resonance frequencies the contact 3 is opened at a point which corresponds to the half of the indicator deviation. If the contact touches the indicator contact, a stroboscopic fluorescent lamp 6 connected to a direct current network flashes briefly.

A mark 10 of bright color is applied to the rotor end in an arbitrary direction serving as a guideline for determining the location of

the unbalanced mass. The indicator connects the lamp in the case of resonance as described above and hence the guideline is observed in an unmoved state and its location is recorded with a mark 11 on the frame body. When the rotor is stopped the mark 10 is brought into coincidence with the mark 11 on the frame; the position of the unbalanced weight is determined by the pointer 9 displaced through an angle of 20° from the horizontal radius in the sense of rotor revolution.

As is obvious from above, the resonance-stroboscopic method developed by N.V. Kolesnikov permits not only the location but also the magnitude of the unbalanced weight to be determined by spinning the rotor once.

Figure 96a shows the scheme of a balancing machine provided with a special phase searcher for marking the location of unbalanced weight in a rotating rotor.

The phase searcher incorporates a solenoid coil 1, a marker 2 - a hollow core filled with a thick coloring mass - the mechanical interlock 3 and two contacts 4 and 5; one of them is mounted in the pendulum frame, the other on the machine plate. The winding of the solenoid, the mechanical-interlock contacts and the contacts 4 and 5 are fed from a direct-current source. The short-circuiting of the contacts 4 and 5 is regulated as follows: when the rotor is at rest they are disconnected and they connect only at frame vibrations which are produced by rotor unbalance at speeds corresponding to resonance frequencies.

When the vibration amplitude of the machine frame is at maximum, the contacts make and complete the circuit of the coil 1. The core is pulled into the coil and makes a colored mark A on the rotating rotor (Fig. 96b). At the same moment the circuit is disconnected by the mechanical blocking and then the core is returned to

its initial position by the spring. After that the rotor is made to run in the opposite sense without changing the gap between the contacts 4 and 5. In a way similar to that described above a second mark B is made on the rotor surface. C, the middle of the arc AB is determined. The unbalanced weight is at the point opposite to C. A rotor can be balanced quickly with frame and pendulum-type balancing machines using the phase searcher.

§61. ELECTRONIC BALANCING MACHINES

Electronic balancing machines, determining the position and the quantity of unbalanced mass by electronic devices, are based on the principle of evaluating the mechanical vibrations set up in the machine by the centrifugal forces of the unbalanced mass during rotation of the rotor, these forces being measured by the emf produced in special pickups.

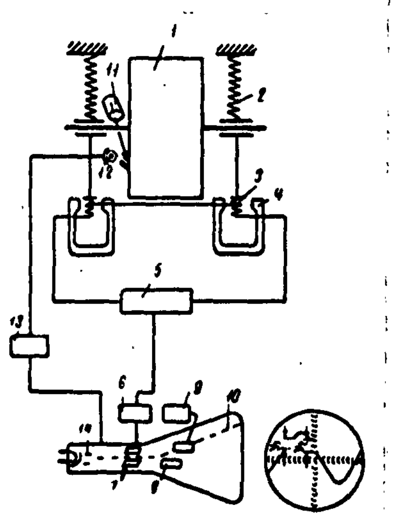


Fig. 97. Diagram of an electronic balancing machine.

Here some electronic balancing machines used for balancing gyromotor rotors are considered.

Figure 97 shows the scheme of an electronic balancing machine. The rotor 1 of the gyromotor is mounted with its bearings in the elastically suspended supports 2 in the machine. The coils 3 are connected to the supports by leaf springs and are positioned between the poles of permanent magnets 4. During rotation of the unbalanced rotor the vibrations of the machine supports are transmitted by the elastic system to the coils, moving them in the field of the permanent magnet so that an emf is induced in them. The emf is proportional to the amplitude of the vibration of the machine support:

$$e = Blv10^{-8} \text{ v.}$$

where B is the magnetic induction in gausses; l is the working length of the conductor, cm; v is the speed of the coil in the magnetic field, cm/sec.

The variation of the emf potential is sinusoidal, having a frequency which is equal to that of the machine support vibrations.

The emf induced in the pickup coils is fed to the Y-plates 7 of the tube, passing through an integrating circuit 5 and an amplifier 6 with a filter which serves to eliminate background vibrations. To determine the support vibrations in dependence on time or on the angular position of the rotor, the X-plates 8 of the tube are fed with the voltage of a special generator 9. Hence a sinusoidal curve is seen on the screen of the oscilloscope tube 10, the amplitude of which characterizes the imbalance of the rotor.

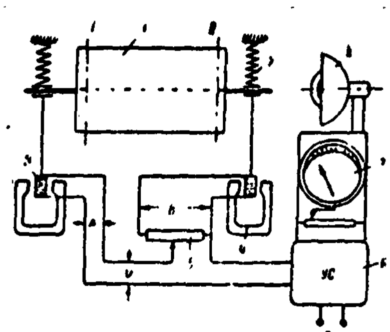


Fig. 98. Electronic machine.

A sinusoidal curve on the screen is only obtained if the signal fed into the amplifier is not only amplified but also has its background oscillations superposed on the sinusoidal one filtered out.

To determine the position of the unbalanced mass, two black reference lines at an angle of 90° to one another are drawn either on the end or on the outer surface of the rotor. During rotation the beam from lamp 11 is reflected from the end, or the outer surface of the rotor, so as to fall upon the photocell 12. In the photocells the light oscillations produced by the black graduation lines are converted into electric current and are fed to the tube grid 14 after having passed through the electronic amplifier 13 where they are amplified. The electron current of the photoelement generated by the

black graduation lines on the rotor damps the main electron current when it arrives at the tube grid.

Consequently the sinusoidal curve visible on the screen of the oscilloscope during one revolution of the rotor shows two gaps indicating the relative positions of the rotor marks and the direction of imbalance.

The ordinates y_1 and y_2 will correspond to the components of imbalance on the diameters passing through the marks on the rotor face.

If the rotor is balanced in one plane, the pickup of the first plane to be balanced is switched off and that of the second plane to be balanced is switched on; whereupon the second rotor plane is balanced in similar fashion.

Gyromotor rotor balancing by means of such an electronic machine is more perfect than balancing with machines based on other principles.

Figure 98 shows the scheme of a balancing machine based on electronics. The rotor 1 to be balanced rotates in the bearings of two elastic, independent supports 2 at a speed of revolution higher than the resonance frequency. Each section of the rotor is balanced separately. The influence of any one rotor section on another is eliminated in the same way as with the machine described above, by switching off the corresponding coils of the pickup of the unbalanced part.

During rotation, the unbalanced rotor 1 produces vibrations of the machine support 2 which is rigidly connected to the coils 3, so that the coils move in the field of the permanent magnets 4 in consequence of these vibrations. Therefore an emf is produced in the coils, amounting to A in the first coil and B in the second.

Every section of the rotor is balanced individually; for this purpose the branch of the circuit belonging to the rotor plane to be

balanced is switched on and the branch belonging to the plane not to be balanced is switched off. This switching is done with a resistor 5 connected into the pickup coil circuit, whereby the coil circuit can be controlled so that voltage equals zero. During balancing of the second plane the influence of the unbalanced first rotor plane is eliminated by switching in a second resistor.

The weights of the balancing loads are determined by sending the pickup signals to the amplifier 6, where they are filtered and amplified; by means of a change-over switch they can be led from each pickup separately to the indicator of the instrument 7, graduated in a previous calibrating test into units that are suitable for correcting the unbalanced mass.

The position of the unbalanced mass in the planes to be balanced is determined by feeding the pickup signals after their amplification in the amplifier through a change-over switch to a special converter mounted in the housing of the amplifier, whereby stroboscopic flashes are produced by the neon tube 8. On the end plane of the rotor or, in some machines, on a special dial mounted on a sleeve round the rotor axis, an orienting point is marked. The position of the load in the first plane to be balanced is determined by comparing the position of the stroboscopic image of the orienting point obtained under the influence of the pulsed neon tube light with the position of an orienting point marked on the stationary frame of the machine. After reversal of the rotor, the position of the load in the second plane is determined similarly.

Before the electronic machine is put into operation, it is adjusted with reference to a standard rotor. A certain test load of plasticine is stuck alternately to the planes to be balanced of the standard rotor, and by varying the resistance the electrical circuit

of the machine is so tuned that presence of imbalance in the first plane to be balanced does not affect balancing in the second plane. This means that the voltmeter used for measuring the signal voltage of the pickup in the one plane to be balanced gives no indication if a test load is applied to the other plane to be balanced. After this adjustment the value of a scale division of the instrument is determined by putting on various loads and the machine can be used for balancing the rotors.

§62. THE "LUNA" ELECTRONIC BALANCING MACHINE

One of the shortcomings of all the balancing machines described above is that the dynamic imbalance of gyromotor rotors is determined

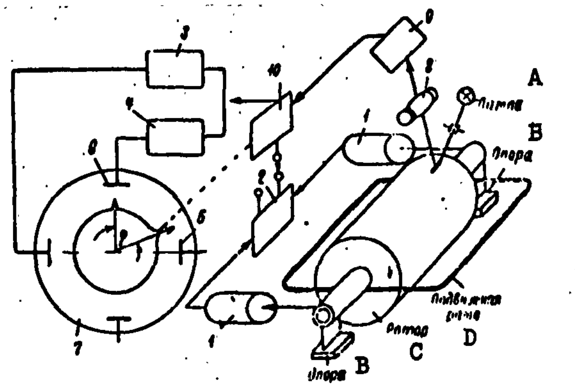


Fig. 99. "Luna" electronic machine: A) Lamp; B) support; C) rotor; D) mobile frame.

at a number of rpm corresponding to the resonance frequency, at speeds which amount to only a fraction of the operational speeds of the same rotors in the assembled gyromotors. It often happens that a rotor exhibiting satisfactory balance at the low speeds behaves as a dynamically unbalanced rotor at normal speeds of operation. This is explained by the fact that at high speeds of rotation the working temperature as well as the rigidity of the axis and of the bearing units of the rotor exerts an important influence on displacement of the cen-

ter of gravity of the rotor. The center of gravity is shifted through the influence of centrifugal forces overcoming the rigidity of the rotor axis and its supports. The vibrations of the rotor are therefore considerably increased at working speeds.

Gyromotors whose rotors are balanced on a "Luna" electronic machine do not suffer from this drawback as the rotors are balanced at operational speeds. The basic diagram of this machine is given in Fig. 99.

The voltage of the electric vibration pickups 1 is fed to computer unit 2; the reduced voltages of this unit can be connected alternately supplied from the different planes to be balanced to the inputs 3 and 4 of the two-channel electronic amplifier. The electromechanical pickups do not differ from those used in the machine described previously.

The circuit of the amplifier ensures the amplification of the signal and shifts the output voltage harmonic of channel 4 through 90° relative to the input voltage harmonic of channel 3. Channel 3 is connected to the X-plates 5 and channel 4 to the Y-plate 6 of the cathode ray tube 7.

Fig. 100. Balancing with an electronic machine.

The result is a circle formed on the screen of the tube by the cathode ray; the diameter of this circle is proportional to the amplitude of the signal, i.e., to the imbalance in the rotor plane to be balanced (according to the position of the change-over switch).

The position of the imbalance is indicated by a coordinate method by means of photocell 8, whose current pulse is amplified by the

amplifier 9 and supplied to the modulator 10 of the cathode ray tube. At the moment when the electric pulse is emitted, a bright spot is produced on the circle described by the cathode ray; its polar angle measured in degrees from the vertical axis of the screen reflects the angular position of the imbalance of the rotor with reference to the mark on the rotor.

Thus the size and position of the point on the circle and consequently the position of imbalance in the plane to be balanced in question can be seen on the screen of the tube.

In comparison with other electronic balancing machines in which the harmonic curves of the vibrations are displayed on the screen, the "Luna" electronic machine offers the following advantages:

1) simple construction (it is not necessary to use an oscilloscope with a scanning generator and a voltage stabilizer);

2) balancing is done at operational speeds (up to 30,000 rpm); the rotor speed need not be constant; no fine tuning is necessary;

3) high accuracy, convenience and clarity in reading the amount and position of the imbalance, and simple evaluation of the indications; good noise suppression.

The "Sperry" firm balances rotors on electronic machines, one of which is shown in Fig. 100. The rotor is driven by a belt running directly over its surface and over the pulley of an electric motor. The position and amount of imbalance producing the vibration are thrown on a screen and determined from the deflection of a ray according to one of the methods described above.

§63. ROTOR BALANCING

The rotor is balanced by drilling holes in it or by soldering metal onto it when stationary; the weight and position of the load must agree accurately with the data obtained from the balancing test on the

machine. Usually the position of the balancing load is determined on a machine having an angular accuracy of 3° and the amount of imbalance can be determined on the scale of the machine with an accuracy of $\pm 10\%$.

In practice it is difficult to ensure the degree of rotor balance necessary as the accuracy of the compensating load is determined by the worker relying only on his experience. This means that a rotor cannot usually be balanced with the required accuracy in one stage. Usually, after the first drilling, it is necessary to put the rotor on the machine once more and to determine the residual imbalance, which has to be eliminated by subsequent drilling or soldering. Because of these inaccuracies in the balancing methods, a rotor has to be spun in the machine three or four times for each plane to be balanced, and the required accuracy is achieved gradually. This is what takes up most of the time in dynamic rotor balancing.

Various methods are used to increase the accuracy and speed of balancing. For instance, tables have been drawn up from which it is possible to read off the weight of the balancing load, during rotor balancing by soldering, from the indications of the balancing indicator or from the scale readings of the machine. The required balancing mass can then be weighed out on an analytical balance and soldered to the rotor at the predetermined position.

In rotor balancing by drilling holes, tables can be used which indicate the dependence of the weight of metal bored out on the boring depth of a drill of given diameter and tip. Since the weight of the metal drilled out corresponds to a given indication of imbalance, a diagram is plotted in which the abscissas correspond to the indications and the ordinates to the depth of the hole in the rotor. The hole is drilled to a depth found from the graph, using a needle indicator with a scale division of 0.002 mm which is connected to the bor-

ing bar. Balancing by this method is completed in two test runs, one main run and one as a check.

In one very convenient method the machine dial, or another indicator, is calibrated according to the imbalance, directly in millimeters of hole depth.

§64. MOUNTING OF BALL BEARINGS

The quality of dynamic rotor balancing does not depend only on the accuracy of the balancing machine and on the proficiency of the worker but also on the accuracy of components in the ball-bearing unit, especially as regards the shape of the axle and the quality of ball-bearing mounting.

Since the residual displacement of the center of gravity of gyromotor rotors has to be very small, and since it depends mainly on the inner ring of the ball bearing not being coaxial with the necks of the axle, the gyromotor rotors have to be dynamically balanced running in the same ball bearings as those in which they will operate. In dynamic balancing of gyromotor rotors no commercial ball bearings should be used.

The fitting of the ball bearings on the neck of the rotor axle is done according to the bore system. The tolerance of the ball bearing bore laid down in GOST [State Standard] 520-55 is negative with respect to the nominal diameter. The fit of the ring on the necks of the rotor axles is of first-class accuracy, so that the ovality – meaning the difference between the maximum and minimum diameter of one cross section – does not exceed half of the neck tolerance, and the taper is only about 0.003 mm.

When the inner ring of the ball bearing is fitted on the neck of the rotor axle a fixed joint must be achieved, tight enough to prevent any possibility of the ring revolving on the neck of the axle during

operation. At the same time the tightness must not be such as to deform the ring. If there is any clearance in the fit of the inner ring, or if the thickness of the ring is not uniform or if both these imperfections are present, the ball bearing will not seat coaxially with the neck of the rotor axle when the ring is tightened by the nut. In this case, an additional dynamic imbalance of the rotor arises.

It is not permissible to fit the ball bearings on the necks or into the seats of the covers and bodies very tightly since there is a possibility that the radial clearance will disappear completely when a gyromotor with radial-thrust ball bearings is running. If the bearings are of the radial-thrust type, considerable additional imbalance of the rotor arises when the direction of the major axis of the possible ellipse of the neck coincides with that of the inner ring deformed under excessive interference.

In the production of rotors, the necks of the axles have to be ground to fit into the bores of the inner rings of the ball bearings with the required tightness, in order to avoid detrimental noncoaxiality (when the ring is fitted with a certain clearance) and the possible disappearance of the radial clearance (when the ring is fitted very tightly).

To find the tightness necessary to ensure that the ball-bearing rings fit accurately on the necks, the following formula should be used (N.S. Acherkan, Machine Parts, Vol. 1, Mashgiz, 1954):

$$\Delta_0 = \text{[illegible]}$$

where Δ_0 is the tightness in mm; p is the radial load taking account of the centrifugal forces produced by the imbalance in kgf; b is the width of the internal ball-bearing ring in mm; r is the corner-radius (chamfer) in mm; N is a dimensionless factor (this factor is 2.78 for

the light type of ball bearings; see "Antifriction Bearings," Handbook).

In gyromotors with precision ball bearings of classes S and A (GOST 520-55) the fits have to be named in accordance with the deviations of the diameters of necks and seats with respect to first-class accuracy. For instance, in the case of axle necks, the S_1 and P_1 fits are to be taken; these can be obtained on the basis of the actual deviations by subsequent grinding of the ball-bearing bores. The P_1 fit is to be taken for rotating rings and the C_1 fit for stationary rings.

Experience shows that the force necessary for fitting ball bearings having a bore of 4 mm must be not less than 2 and not greater than 8 kgf in order to fit the inner ring on the neck of the rotor axle without deformation but nevertheless tightly enough. The force necessary for fitting ball bearings with a bore of 5 mm must be not less than 5 and not greater than 15 kgf. The outer rings are pressed into the seats of the covers and bodies with a force of not less than [illegible] and not more than 700 gf.

When the rotor necks and the inner ring bores are worked to secure first-class accuracy it is possible that the tolerances of the parts to be mated will add to produce an effort required to fit the ring on the neck which may be considerably greater than that allowed. It must be taken into account that tightness arises not only from differences between neck and bore but also from tapering and ellipticity of neck and bore of the inner ring of the ball bearing; especially if the major axes of the ellipses of both parts happen to coincide. Calculation and practical data both indicate that a tightness of 1 μ requires a force of 3 kgf; for fitting a tightness of 2 μ a force of 9 kgf and one of 3 μ a force of 21 kgf.

In mounting the ball bearings in the seats and on the necks, no force may be transmitted through the balls as this might cause deformation spots on the balls and hollows on the rings; such deformations affect the precision of rotor balance and efficiency of the ball bearing.

To ensure that the forces necessary for fitting the ball bearing ring onto the neck fall within the limits stated above, either the rings must be fitted to the necks or vice versa.

The bore of the inner ring is matched up with the neck in the following way: after the ball bearings with the certified inner ring bore diameters has been obtained, the necks of the axles are finally ground in accordance with these bores so as to ensure the required tightness. The bores of the inner rings of the ball bearing are certified at the manufacturing plant and their deviations are determined with a graduation of 2 μ. Every ball bearing receives a rating plate giving the deviations of the inner ring besides the main data.

In the absence of a rating plate for the ball bearing, grinding the neck and matching up the ring are rendered difficult; the tightening cannot be done with the necessary precision and the assembled rotors are often defective. To accelerate the process of grinding the necks and of matching them up with inner rings of the ball bearing, the latter are certified in the plant where the gyromotors are manufactured. Certifying the ball bearings is considerably less expensive than matching up the rings with the necks without having determined the deviations of the bores beforehand. Several apparatuses are available for measuring the inner ring bores, which ensure the necessary accuracy of measurement.

Figure 101 shows the layout of a pneumatic floating device made by the "Kalibr" plant for determining the diameter, ovality and taper

bore of the inner ball bearing rings with a diameter of 2 mm and more.

This TGPZ-2 device consists of a filter 1, two pressure regulators 2 and 3, a valve 4, a settler 5 with a drainage tap 6, a tapered glass tube 7 with a float 8 and a scale, an outlet valve 9 and the interchangeable gage 10.

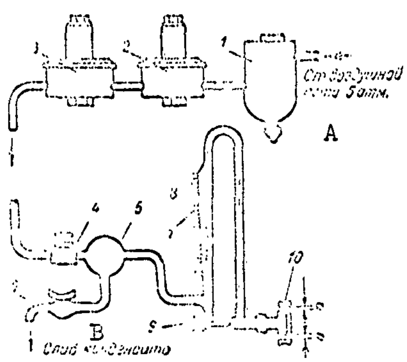


Fig. 101. Diagram of a pneumatic instrument for checking the bores of the inner ball bearing rings. A) From air line 5 atm; B) discharge of the condensate.

This device is based on measuring how the quantity of air flowing out into the atmosphere depends on the size of the gap between the faces of the gage and the bore of the inner ball bearing ring to be checked. A variation in the quantity of air flowing out changes the position of the float; the air stream passing through the tapered glass tube keeps the float in a position at which the annular gap between the float and the inner walls of the tube corresponds to the efflux of air. The size of the bore is estimated by comparing the position which the float takes up for the test piece with its position established for a standard and marked on the scale, which is taken as the beginning or end of the reading. The beginning and the end of the reading are determined according to two standard bores. The lower indication, which corresponds to minimum dimension of the bore to be measured and to the lower position of the float, is marked on the scale of the instrument in accordance with one standard bore. The upper indication, which corresponds to the maximum dimension of the bore to be measured and to the upper position of the float, is marked on the scale of the instrument in accordance with the other standard bore. A scale is made of paper for every dimension of ring bore and is divided into equal sections for appropriate measure-

ments; for precise measurements, the scale is divided into sections corresponding to the particular shape of the tube.

The regulator of the instrument is intended to reduce the pressure and keep it constant when the pressure in the air line fluctuates. The settler serves to collect condensed moisture which is drained off through the tap. The outlet valve enables part of the air to be admitted directly to the gage, bypassing the tapered tube.

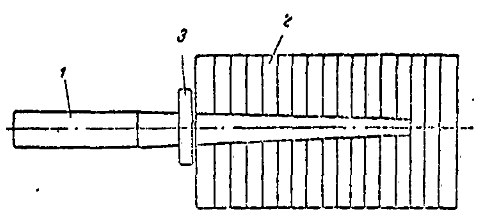


Fig. 102. Checking the inner ring bores by means of a tapered mandrel. 1) Tapered mandrel; 2) graduated scale; 3) ball bearing.

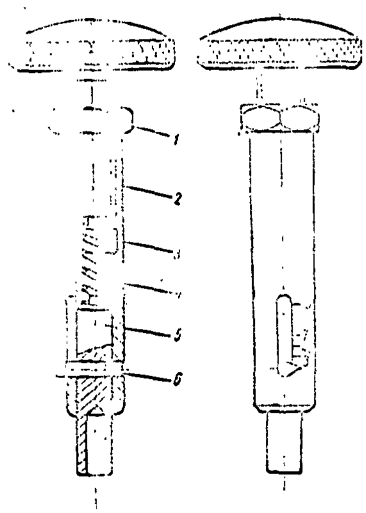
Adjusting the valve alters the scale of magnification of the instrument. The ball bearing bore diameter is checked as follows: after the device has been calibrated with the two standard rings, the gage is inserted into the ring bore to be measured and valve 4 is opened to admit air. The air escapes into the atmosphere against a certain resistance in the gap between gage and ring. The air efflux through any given gap between the gage and the ring bore causes a certain displacement of the float in the glass tube with the scale. The position of the float is read off the scale, which makes it possible to determine in microns the deviation in the diameter of the ring bore to be measured.

Due consideration is given to the measurements on the inner ring bore diameters when grinding the rotor necks, which ensures that the rings are fitted on the necks of the rotor axles with the required force.

If the plant manufacturing the gyromotors has no device for measuring the bores of the inner rings of the ball bearings the rings are certified by means of tapered-gage measurement. The set of gages for

each type of ball bearing consists of several tempered and ground tapered steel mandrels (Fig. 102) with a taper of 0.01 mm.

The ring bores are certified by means of the gage as follows: the ball bearing to be measured is pushed onto a tapered mandrel as far as the inner ring bore allows, and the deviation of the ring bore diameter is then determined by means of a calibrated rule (depending on how far the ring has been pushed onto the mandrel).



. g. 103. Dynamometer .. fitting inner ball ...ring rings on the ..ecks of rotors. 1) ..t; 2) plunger; 3) . ay; 4) spring; 5) punch; 6) pin.

For more accurate deviation measurements, the rules are calibrated for each mandrel separately. This makes it possible to determine the ring diameter with an accuracy of up to 2 μ, which is sufficient to show for which deviations it is necessary to grind the necks of the rotor axles in order to ensure that the ball bearings fit with the required tightness.

The results of the measurements of the bore diameters of the inner ball bearing rings are compiled in a table which is handed on to the machine shop, so that the desired number of necks can be ground down to a size ensuring the necessary tightness.

During assembly, the rotors with their necks ground according to the size of the rings are placed in the bal...ing frame with the corresponding ball bearings. Even so, it is not always ensured that the inner ball bearing rings fit with the necessary tightness, because the necks are apt to become tapered, oval, locally flattened and wavy when they are ground. Even if these defects fall within tolerable limits, their coincidence with corresponding defects in the ring bore may increase the fitting pressure of the ball

bearing on the neck. Therefore the inner rings are fitted on the necks by means of a dynamometer (Fig. 103) as follows.

After the inner ring has been put on the neck of the rotor axle, it is inserted into a special recess in the dynamometer. The handle of the dynamometer is pressed with the palm of the right hand so that the spiral spring inside the handle is compressed.

Then the dynamometer reading on the scale graduated in kilograms on the body is noted. If the ball bearing ring does not fit the neck of the axle when it is pressed by means of the dynamometer with a force slightly greater than permissible, it will not be pressed onto the neck; it is transferred to another neck onto which it is pressed with the permissible force read on the scale of the dynamometer. Sometimes the ring can be fitted with the allowed force if it is turned through 90° or 180° with respect to the initial position on the neck. This can be explained for instance if the ellipticities are such that the minor axis of the ellipse of the neck coincides with the major axis of the ellipse of the ring bore. If the ring fits on the neck with a force less than permissible, it will be transferred to another neck, and another ring ensuring the necessary tightness of fit will be fitted to the original neck.

When choosing rings for the necks, one has to consider that the ovality of the necks can cause an additional imbalance of the rotors. When the ball bearings are being mounted, it is therefore necessary to position the rings in such a manner that the directions of the major axes of the ellipsoidal neck and ring bore are perpendicular; this can be achieved by measuring the neck or trying out the fit of the ball bearing on the neck by hand beforehand. The rotor is assembled with its ball bearings in the balancing frame and balanced dynamically on a balancing machine.

ASSEMBLY OF THE BALANCING FRAME WITH THE ROTOR

Figure 104 shows one of the frames for the dynamic balancing of gyromotor rotors on balancing machines. The frames must be light and sufficiently strong. They are usually made out of D1T or D16T circular

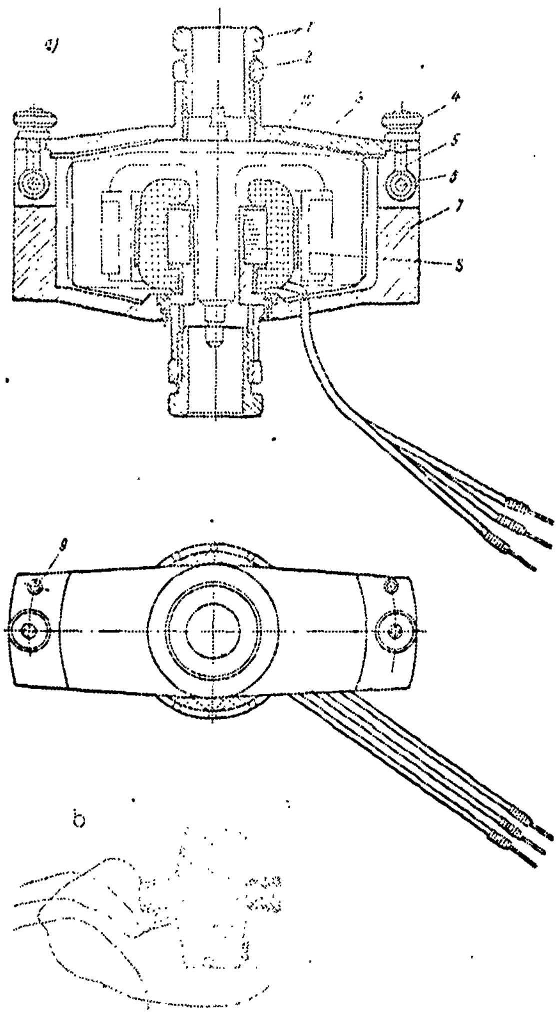


Fig. 104. Balancing frame: a) Section; b) over-all view. 1) Bush; 2) lock nut; 3) cover; 4) nut; 5) swing bolt; 6) axle; 7) body; 8) stator; 9) pin; 10) rotor.

duralumin rods. The outer surfaces are machined first, and then the hole for the rotor is drilled out. The hole for the stator bush is

drilled in the back wall of the body of the frame, and the hole for the ball bearing in its rear part. The side faces of the body are then milled on both sides, which gives the frame its П-shape. The gyromotor stator with winding is placed in the hole in the back wall of the body of the frame and screwed fast, and the end connections of the winding are connected to the terminals of the machine during balancing. Swing bolts, with round nuts, free to turn on their axles are placed in the milled recesses of the body to hold the lid to the body.

The lid is made of the same material as the body; the lid is machined on both sides, and then sectors are milled off so as to give it the shape shown in the figure. By its catch, the cover is set on the slots of the frame body and then fixed with pins. When the cover has been adjusted, it is fixed to the body with swing bolts which are introduced into the recesses of the body and pressed against the latter with nuts. Adjusting bushes are screwed into the rear part of the body and the lid for regulating the axial clearances of the ball bearings fitted into the drilled holes together with their outer rings. When the axial clearances or tightnesses necessary for balancing have been adjusted, the bushes are fixed with lock nuts.

Before the rotor is fitted in the frame, the ball bearings which have been matched up and washed in aviation gasoline are pressed onto its necks. Washing is performed by consecutive immersion in three small baths made of glass or porcelain.

After the ball bearings have been washed and dried in air, they are wiped with condenser paper and their parts examined under a lens with a 6-fold magnification to see if mechanical defects, traces of corrosion, or metallic foreign bodies in the separator are present.

The rotor necks are also washed in pure aviation gasoline, dried in air, and wiped with clean new batiste cloth containing neither

...ams nor lint. The dry rotor necks are inspected under a lens with 6-fold magnification; no dust, nicks or metallic foreign particles may be present at the positions where the inner rings of the ball bearings are fitted on. The rotor neck is lubricated with TsIATIM-202 grease, and a mark is made on its open side above the inner ring of the ball bearing. Meanwhile, the opposite rotor neck rests on a metal support with soft material glued on to it, or on a wooden support. The inner ring is pressed onto the neck of the rotor axle until it is stopped by means of a calibrated dynamometer (see Fig. 103).

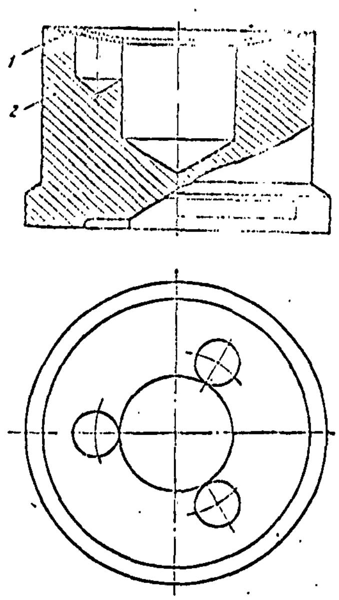


Fig. 105. Socket. 1) Packing; 2) socket.

When the ball bearing ring has been pressed onto the neck of the rotor it is fixed with a special nut. The face of the ball bearing ring must not be distorted relative to the face of the shoulder of the rotor axle.

One method of testing whether the inner ring of the ball bearing is correctly fitted is to check whether any light can pass between the face of the ring and the neck of the rotor axle. For this purpose the ball bearing ring is placed in front of a source of light and the fit observed. If the ring has been pressed on correctly, no light can penetrate at any point on the periphery. If there is a uniform gap round the whole periphery between the ring and the neck of the axle, the ring must be pressed on more firmly by pressing the dynamometer handle, if the fitting force permits.

If light passes between the face of the inner ring and the shoulder at isolated points, or if there is a gap resulting from poor

hollow chamfering on the shoulder, then the ball bearing ring must be taken off the neck by means of a stripper and the cause of the bad fit determined and eliminated.

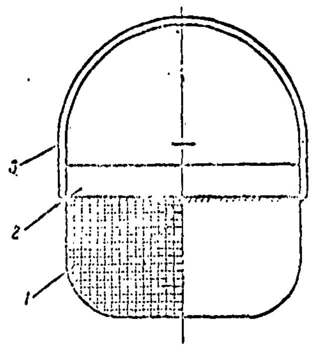


Fig. 106. Net for washing the balls. 1) Net; 2) ring; 3) handle.

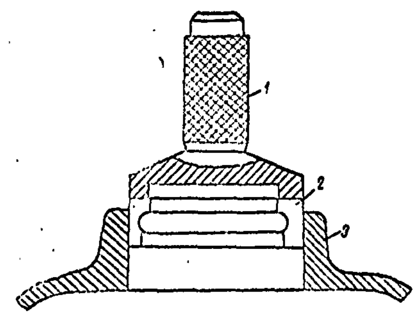


Fig. 107. Mandrel for placing the outer ring in position. 1) Mandrel; 2) outer ring; 3) body.

When the ball bearing ring has been pressed on, the rotor is assembled with the balancing frame (Fig. 104), which is previously wiped with a cloth moistened with gasoline. The rotor is placed on a socket (Fig. 105) with the stator opening pointing upwards, and the stator and its winding are put inside. The stator unit is pressed to the frame in such a way that the neck of the axle with the inner ring of the ball bearing pressed onto it fits into the hole for the ball bearing in the frame. The snap ring, the outer ring and the balls of the ball bearing are washed by immersing them 5 or 6 times in three consecutive baths containing aviation gasoline. The balls are put in a special net (Fig. 106). When the snap ring, the balls and the outer ring have been washed and dried in air, a thin layer of TsIATIM-202 grease is applied using a special cloth made of LSh-1 varnished fabric.

The inner ring is pressed onto the neck, and the snap ring and the balls are set in position on the race of the inner ring through

the hole drilled in the frame for the ball bearing; the outer ring of the ball bearing is pressed on the balls using a mandrel (Fig. 107), and fastened to the frame with the bearing nut. Ball bearing rings or balls should not be interchanged with the corresponding parts of other ball bearings, since the ball bearings are supplied with rings and balls which are not mutually interchangeable.

The ball bearing in the cover of the frame is mounted in the same way. The cover is fastened to the frame with nuts and fixed in a definite position with pins.

Ball bearings should not be struck when being mounted. Mounting and dismounting of ball bearings should be carried out using devices that ensure that the rings fit smoothly on the necks of the axles in the openings in the frame, body and cover.

When the rotor has been assembled with the balancing frame, there should be no axial clearance. The rotor must be in the center of the frame, which is achieved by adjusting the bearing nuts on the frame.

§66. TECHNIQUES OF DYNAMIC BALANCING

It has already been mentioned above that the dynamic balancing of gyromotor rotors is most often performed by attaching small loads. Compared with other methods, this method of balancing is reliable and sufficiently precise, but is comparatively lengthy. It is based on measuring the maximum vibration of the balancing machine supports. The more the balancing load approaches the necessary weight, and the more it approaches the correct position on the rotor, the smaller the vibrations of the machine supports become. When a load of the required weight assumes the correct position, the vibrations of the machine support with the rotor attain a minimum.

As shown in Fig. 94 and described above, dynamic rotor balancing by this method on a balancing machine consists of determining the cor-

rect position and weight of the balancing load. The position of the load is determined by measuring the deflection of a pencil of light on the scale of the machine when the amplitude of the support vibrations is a maximum, i.e., when the rotor is rotating with a speed of revolution corresponding to the resonance frequency; it is found by displacing the test load on the periphery of the rotor in the planes to be balanced.

The size of the balancing load can also be determined by measuring the maximum amplitude of vibration of the machine supports (on a graduated scale); in this case, the position on the rotor periphery in the planes to be balanced remains the same for various loads.

To find the correct position of the balancing load on both ends of the rotor quickly, four marks, numbered 1, 2, 3, and 4, are made on the outside spaced at 90° round the circumference (Fig. 108).

The sensitivity of the balancing machine on which the rotors are balanced or the residual imbalance is determined must correspond to the admissible imbalance of the rotor. The sensitivity of the balancing machine is determined as follows: the rotor mounted in the balancing frame is balanced in such a way that when the balancing frame is in a given vertical position and is turned through 180°, the value of the residual imbalance on the side of each rotor plane to be balanced is characterized by the width of the beam of light being about twice as wide as it was before rotor was mounted in the frame, when the rotor revolves with a speed corresponding to the resonance frequency. A rotor balanced in this way can be used as a standard for later checks on the sensitivity of the machine.

An additional load of plasticine is then fastened in turn to the marks 1, 2, 3, and 4 spaced at 90° round the circumferences of the ends of the standard rotor. The load should increase the imbalance of

the rotor by a value that is characterized by the admissible number of scale divisions on the balancing machine. The load removed from the rotor is weighed with an accuracy of 0.0001 kgf. The load Q is deter-

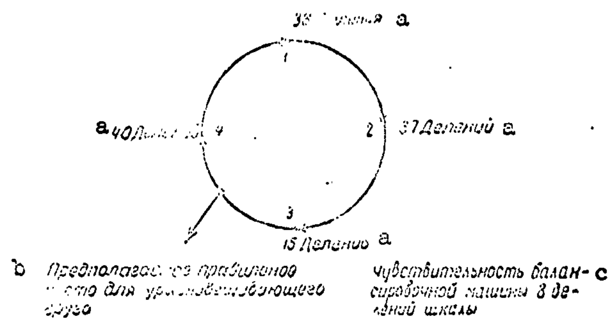


Fig. 108. Diagram of determination of the position of the load on the basis of the deflection of a beam of light on the scale of the machine when the rotor is unbalanced. a) Divisions; b) estimated correct position of the balancing load; c) sensitivity of the balancing machine amounts to 8 scale divisions.

mined from the permissible imbalance of the rotor laid down in the design or the technical specifications of the gyromotor in question by the following formula:

$$Q = \frac{D}{RL},$$

where Q is the load in gf; D is the admissible imbalance in gf·cm^2;* R is the radius of the rotor planes to be calculated in cm; L is the distance between the rotor planes to be balanced.

The amount by which the beam of light is deflected when the unbalanced load Q is fixed to the rotor determines the sensitivity of the balancing machine in scale divisions for the admissible imbalance D. The multiplying factor of the balancing machine is calculated from the formula

$$A = \frac{D}{C},$$

where A is the multiplying factor of the machine scale in gf·cm^2; D is the admissible imbalance; C is the number of scale divisions covered when the light beam is deviated due to the admissible imbalance D.

When the sensitivity of the balancing machine has been checked, the rotor to be balanced, assembled with its frame, is mounted in the frame of the balancing machine, and the stator winding connected to the terminals of the machine. The appropriate voltage is applied to the latter at high frequency. The voltage is sent through the three-phase winding of the stator by pressing the starter button.

The rotating magnetic flux set up in the stator interacts with the shunted winding of the rotor and begins to carry the latter along with it.

The number of rpm of the rotor rises gradually and reaches the resonance frequency. The starter button is then released, thus switching out the stator winding, and the number of rpm of the rotor begins to decrease. The magnitude of the imbalance is determined from the deflection of the beam of light on the scale of the balancing machine at the moment when the number of rpm corresponds to the resonance frequency, i.e., when the amplitude of vibration of the machine supports is a maximum. The amount of imbalance is first determined on the same side as the cover and then on the same side as the frame of the body. When the magnitude of the imbalance for both sides has been recorded, one starts balancing the rotor on the side indicated by the greatest deflection of the beam of light from its zero, i.e., middle position on the scale. This is done by applying an additional load of plasticine with a wooden spatula in turn to the points marked 1, 2, 3, and 4 on the rotor plane to be balanced, 1-2 mm from its end, and determining the maximum deflection of the beam of light from the zero position on the scale of the machine for each point. The deflections of the

beam of light are determined at the instant at which the rotor is revolving at a number of rpm corresponding to the resonance frequency.

When the imbalance at all four points of the rotor plane to be balanced has been tested, a sector is determined in which the amount of imbalance (deflection on the scale) is smallest (Fig. 108) at a number of rpm corresponding to the resonance frequency. The minimum deflection of the beam of light on the scale is found by displacing the load along the circumference of the rotor in this sector. Minimum deflection of the beam is achieved by increasing or decreasing the load.

Balancing the rotor by displacing the load and changing its weight is continued until the residual imbalance of the rotor corresponds to the admissible deflection of the beam of light on the scale of the machine. When the imbalance of the rotor plane to be balanced permitted by the technical specifications has been reached on one side, balancing is then carried out on the other side, also until the corresponding deflection of the beam on the scale has been reached. The balance of the first plane is then checked, and if the balance of this plane has been disturbed, the plane is additionally balanced by changing the position and weight of the load. Main balancing and additional balancing should be carried out without changing the position of the balancing frame in the vertical plane. The frame is then turned through 180° together with the rotor, and both of the rotor planes to be balanced are tested in the vertical plane until balance is reached. If the imbalance estimated on the basis of the deflection of the beam of light on the scale has increased in any one plane, then this plane is additionally balanced. The difference in imbalance occasioned by turning the frame through 180° should not exceed 0.5 scale division. If the difference in imbalance after additional balancing is greater

than this, then one of the ball bearings must be changed, and the rotor must be balanced in both planes all over again.

When balancing is complete, the stator winding is disconnected from the terminals of the machine, and the frame and rotor are removed. Graduation lines not longer than 2 mm are scratched on the side of the rotor with a marker, diametrically opposite to the plasticine loads. The rotor is placed on a prism with the mark uppermost, and a center is placed at the center of the mark. Then, care being taken not to move the load, the excess metal is bored out using a 2-mm drill. The weight of metal drilled out must be equal to the weight of the plasticine load. The hole must therefore be drilled gradually, and not very deep, and the results tested on the balancing machine. The admissible imbalance of the gyromotor is not usually more than one scale division. When the metal has been removed, the plasticine loads are removed from the rotor planes to be balanced. The sharp edges of the drill-holes are smoothed. The holes are not usually bored to a depth greater than 2 mm. If one hole is insufficient to achieve admissible imbalance in the rotor, two or three holes have to be drilled out next to one another. The metal is removed from the second balancing plane of the rotor in the same way.

To prevent shavings and metal dust from penetrating into the ball bearings, the rotor is covered with thin felt or leatherette during boring, and the spindle is equipped with a special suction attachment; this consists of a device which is fastened to the lower part of the spindle, an oil filter, and a suction pump or vacuum cleaner connected to the device by a rubber tube. Figure 109 is a diagram of the attachment.

The device consists of a hollow body 1, fastened to the end of the spindle of the drill. The movable bush 2 slides freely in the

body. The drill 3, fastened in a draw-in attachment, passes through the bush. The spring 4 presses the bush on the rotor. A tube is attached to the hollow cylinder through the adapter 5. The other end of the tube is attached to the vacuum cleaner or to the intake adapter of the oil filter 10. The air passing through the chamber 8 containing the oil and the net 9 is cleaned of shavings and dirt. The vacuum pump

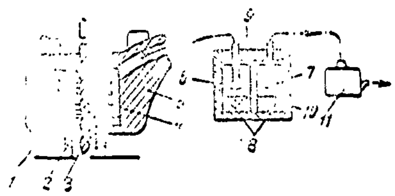


Fig. 109. Drilling machine attachment to prevent shavings from falling into the ball bearings when drilling metal out of the rotor.

11 is connected to the intake and outlet adapters 6 and 7 of the oil filter. The vacuum cleaner or suction pump is set in motion at the same time as the drilling machine. Shavings and metal dust are sucked off from the drill into the oil filter or into the chamber of the vacuum cleaner. When the drilling machine is switched off, so is the vacuum cleaner or suction pump.

To prevent corrosion after balancing the rotor, all the holes are covered with quick-drying anticorrosive varnish and the balance of both planes tested once more. If necessary, the rotor is balanced additionally.

When the rotor has been finally balanced, the bearing nut is screwed out of the lid of the frame, and the outer ring of the ball bearings is taken out, together with the snap ring and the balls. The parts of the ball bearings are wrapped in lint-free paper. The nuts are slackened, the swing bolts tilted out of the recesses of the lid and the lid is removed from the body of the frame. The bearing nut is unscrewed from the body of the frame, and the outer ring, snap ring and balls are taken out and wrapped in lint-free paper. The wrapped parts of the ball bearing are placed in the rotor, and the ground surface of the rotor is wiped with a batiste cloth moistened with gaso-

line. The rotor and its components are placed in a desiccator containing silica gel and stored there until reassembled.

§67. LUBRICATION OF BALL BEARINGS

Liquid or solid lubricants are used for the ball bearings of gyromotors, and in special cases a mixture of both. The main aims of lubrication are:

a) to reduce the sliding frictional force between the moving bodies (balls) and the snap ring;

b) to reduce the sliding frictional forces set up by elastic contact deformation under the effect of the load;

c) to prevent corrosion of the high-quality surfaces of the races, the working surfaces of the rings and also the other surfaces;

d) to fill up the gaps between the rotating and stationary parts of the unit, which protects the ball bearing from penetration by dust, moisture and foreign bodies;

e) to promote an even distribution of heat between all the parts of the ball bearings, and to carry away heat produced by frictional work.

Requirements Imposed on Lubricants

The lubricants used in gyromotor ball bearings must satisfy the following demands:

a) the greases must be physically and chemically stable;

b) the lubricant may contain neither mechanical impurities nor water; however small they may be, foreign bodies act as abrasives and accelerate wear in ball bearings;

c) the lubricants may not give rise to any corrosion, and must prevent it. The lubricant may therefore contain neither free acid nor any other corrosive agents; it must be neutral or slightly alkaline;

d) the internal friction of the lubricant must be a minimum,

since it causes energy losses at high rpm, and this leads to a high working temperature in the ball bearing;

e) solid lubricants must have favorable yield properties, and must offer sufficient resistance to the centrifugal forces which tend to sling the lubricant out of the ball bearing. They may neither separate into their components nor deposit soap which may harden and render the ball bearing unserviceable (the lubricant must retain its initial consistency, yield properties and fiberless structure in operation);

f) the lubricant must be smooth, fiberless, homogeneous and adhesive, since it is only adhesive lubricants that can cover the working surfaces with a thin film and not be sprayed out by centrifugal forces;

g) the viscosity of the liquid mineral oils and the mixtures of solid lubricants and liquid oils must not vary sharply during operation and under the influence of temperature changes in the surrounding medium.

Lubricants Used in Gyromotors

Either liquid mineral oils or mixtures of liquid oils and solid lubricants or solid lubricants may be used for the lubrication of gyromotor ball bearings, depending on the operational conditions and the structure of the bearing unit.

Liquid lubricants are used for Cardan units and in gyromotors with wick lubrication. In low-power gyromotors where the frictional losses in the ball bearings must be as small as possible and which must also operate for a long time without being refilled, a liquid-solid lubricant mixture with a given component ratio is used. The mixture must have the viscosity necessary to ensure that it does not flow out of the ball bearing and that the increase in friction is small.

Solid lubricants are used in most types of gyromotors. These consist of a thin emulsion of mineral oil in calcium soap or some other soap. The performance properties of solid lubricants, i.e., softening point (drop point), consistency or penetration, and its other physicochemical properties depend on the quantity and nature of the soap used, and also on the mineral oil component of the lubricant. One of the advantages of solid lubricants which should be mentioned is that they do not flow out of the ball bearing whereas they do fill the gaps between the moving and stationary parts of the ball bearings satisfactorily. Their drawbacks include their high coefficient of internal friction and their unstable quality.

The universal lubricant does not exist. Where one lubricant produces satisfactory results another may prove useless. When a lubricant for a gyromotor is being selected, the conditions under which the ball bearing units are to work must be carefully studied and compared with the characteristics of the lubricants.

The following are the most important of the factors to be taken into account when choosing a lubricant: 1) speed of revolution (number of rpm and dimensions of the ball bearing); 2) load on the ball bearing; 3) state of the surrounding medium; 4) working temperature of the ball bearing unit; 5) working life of the bearings.

The principal parameters of the lubricant which must correspond to the conditions under which it is used include drop point, penetration (consistency), acid and alkali content, mechanical impurity content, water content, ash content, and corrosive activity.

The drop point makes it possible to judge whether the lubricant can retain its consistency at working temperatures.

The viscosity of the lubricant is characterized by the time it takes to flow out, and is defined as the ratio between the time taken

TABLE 11

Physicochemical Properties of Lubricants

1 Свойства	2 Наименование и марка смазки					
	3 ЦИАТИМ-201	3 ЦИАТИМ-202	4 ОКБ-122-12	4 ОКБ-122-7	4 ОКБ-122-16	5 Методы испытания
Вязкость при 50° С: 6 кинематическая, *сст* соответствующие ей условия, °ВУ	— —	— —	— —	— —	19—23 2,83—3,56	7 ГОСТ 33—53 Приложение 2К, ГОСТ 33—53
Пенетрация: 8 при температуре 25° С » » 60° С	270—320 50	285—315 20	—	—	—	9 ГОСТ 5346—50
10 Температура каплепадения не ниже °С	170	170	150	160	—	9 ГОСТ 6793—53
11 Температура вспышки (определяемая в открытом тигле °С)	—	—	—	—	17	—
12 Температура застывания не выше. °С	—	—	—	—	—70	9 ГОСТ 1533—42
13 Кислотное число в *мг*·КОН на 1 *г* смазки, не более	14 После окисления 1,0	—	—	—	0,25	9 ГОСТ 5985—51
15 Содержание свободных щелочей в пересчете на ОН не более, %	0,1	0,1	0,15	0,03	—	9 ГОСТ 6707—57
16 Температура затвердевания не выше, °С	—	—	—70	—70	— 17	По п. 4 [illegible] на смазку ОКБ-122
Термическая стабильность: 18 выделение масла (синерезис) не более, % 23 испаряемость не более, % 25	19 При 100° С за 50 час. 4 4	20 При 75° С за 24 часа 3—5 —	21 При 50° С за 48 час. 1,5 —	 2,5 —	 — —	22 ГОСТ 263[illegible] для ЦИАТИМ-201 по п. 3 24 ГОСТ 6267—52 п. 3, ГОСТ 6267—52
26 Испаряемость при толщине слоя 0,1 *мм* при 50° С в течение 100 час. не более, %	—	—	3,5	3	—	27 По п. 5 ТУ на смазку ОКБ-122

28 Химическая стабильность. Снижение давления в $\kappa\Gamma/см^2$ при окислении смазки в бомбе под давлением кислорода 8 $\kappa\Gamma/см^2$, температуре 100° С в течение 100 час., не более	0,35	0,5	—	—	—	ГОСТ 5731—53
Подвижность смазки при —60° С на оборот подшипника не более, сек. 29	10	—	—	—	—	30 По п. 4. ГОСТ 6267—52
Содержание воды, % 31	Отсутствие 32					19 ГОСТ 2477—44
33 Содержание механических примесей, %	Отсутствие 32					9 ГОСТ 637—52
34 Испытание на коррозию металлических пластинок (ст. 40, Л62, Д1-Т) при 50° С в течение 48 час.	35 Выдерживать					36 Консистентные смазки по ГОСТ 1037—41; масло по ГОСТ 2917—45
37 Испытание на коррозию при 100° С в течение 3 час.	35 Выдерживать					9 ГОСТ 5757—51

1) Properties; 2) name and type of lubricant; 3) TsIATIM; 4) OKB; 5) testing methods; 6) viscosity at 50°C: kinematic, cst; corresponding conditions, °VU; 7) GOST 33-53, supplement 2K, GOST 33-53; 8) penetration at 25°C, at 60°C; 9) GOST; 10) minimum drop point °C; 11) flash point, °C determined in open crucible; 12) maximum freezing point, °C; 13) maximum acid number in mg KOH per g of lubricant; 14) after oxidation 1.0; 15) maximum percentage of free alkalis on conversion to OH, %; 16) maximum solidification point, °C; 17) according to paragraph 4 TU for OKB-122 lubricant; 18) thermal stability: separation of oil; 19) at 100°C in 50 hours; 20) at 75°C in 24 hours; 21) at 50°C in 48 hours; 22) GOST 2633-48 for TsIATIM-201; 23) maximum syneresis, %; 24) according to paragraph 3 GOST 6267-52; paragraph 3 GOST 6267; 25) maximum volatility, %; 26) maximum volatility in 0.1 mm layer at 50°C after 100 hours, %; 27) according to paragraph 5 TU for OKB-122 lubricant; 28) chemical stability, drop of pressure in kgf/cm^2 on oxidation of the lubricant in a bomb under 8 kgf/cm^2 oxygen pressure, at 100°C for 100 hours maximum; 29) mobility of lubricant at -60°C per turn of the bearing, maximum, sec; 30) according to paragraph 4 GOST 6267-52; 31) water content, %; 32) nil; 33) content of mechanical impurities, %; 34) corrosion test of metal plates (40, L62, D1-T steels), at 50°C, for 48 hours; 35) passed; 36) solid lubricants according to GOST 1037-41; oil according to GOST 2917-45; 37) corrosion test at 100°C for 3 hours.

for a given quantity of the lubricant to flow through a calibrated orifice and the time taken for water to flow through the same opening at a given temperature. The greater the viscosity, the greater its characteristic number. Viscosity is not a constant value: it decreases with rising temperature in a way whose character depends on the nature of the lubricant.

Lubricants are also characterized by physical parameters such as the kinematic viscosity.

The <u>kinematic viscosity</u> is defined as the ratio between the dynamic viscosity of the liquid and its density at the temperature of measurement. The unit of kinematic viscosity is the stoke (st); the hundredth part of this is the centistoke (cst).

The penetration, which characterizes the consistency of the lubricant, is determined in a penetrometer whose operation is based on measuring the depth to which a cone with an angle of 90° and a weight of 150 gf penetrates into the lubricant to be tested in the course of 5 sec. The penetration takes place at a given temperature, e.g., 25°. The depth of penetration of the cone expressed in tenths of a millimeter is the degree of penetration characterizing the lubricant in question. The greater the penetration, i.e., the deeper the cone penetrates into the lubricant, the softer the lubricant.

The practical significance of the penetration is that it makes it possible to pass judgment on the access of the lubricant to the surfaces to be lubricated, and also on internal friction which determines the operation of the gyromotor, and in particular its running-down time.

When lubricants are chosen in gyromotor manufacturing practice, the degree of penetration is often disregarded, since it is looked upon as unimportant. But a small change in its value can lead to the

rejection of whole batches of gyromotors. In one gyromotor factory, for instance, about 70% of the gyromotors were rejected on testing one batch because the time they took to run down was too short. The next series was rejected for the same reason. It is well known that the running down time is affected by many parameters, such as the quality of the ball bearings, particularly the finish of their races and their axial tightness, etc.

All the parameters were examined carefully to determine the cause of failure, a process which took up a great deal of time. It was found that the factory supplying the lubricant had delivered a batch of solid lubricant with a penetration much lower than that hitherto, since the technical specifications allowed the value of the penetration to vary within wide limits. When a lubricant with higher penetration had been prepared and used in the gyromotors, the running down time returned to within the admissible limits.

For gyromotors running at high speeds under heavy loads, the appropriate lubricant for a wide temperature range can be finally found only after longevity tests on the gyromotors, using the lubricant recommended as corresponding to requirements of the technical specifications.

The characteristics of some lubricants used for ball bearings in gyroscopes are given below.

TsIATIM-201 (UTVMA) is a universal, high-melting, water-resistant, freeze-proof, activated lubricant (GOST 6267-52). The lubricant is solid, homogeneous and light to dark yellow in color. The working temperature range is -50 to +120°.

TsIATIM-202 is a homogeneous, soft solid lubricant, yellow to bright yellow in color. Working temperature range, -50 to +150°. Supplied according to TU 517-54.

OKB-122-7 is a homogeneous solid lubricant, containing OKB-122-16 oil, thickened with high-melting ceresin and stearin. Working temperature range from -50 to +120°. Supplied according to US Technical Specifications (AMTU) 351-55.

OKB-122-12 lubricant, a homogeneous grease, containing OKB-122-14 and MS-14 oils, thickened with high-melting ceresin. Working temperature ranges from -60 to +120°. Supplied according to US Technical Specifications (AMTU) 353-55.

OKB-122-16 oil, composed of organosilicon liquid and highly refined mineral oil. Working temperature ranges from -60 to +100°. Used for Cardan units and gyromotor ball bearings with wick lubrication.

The physicochemical properties of these lubricants are given in Table 11. In low-power gyromotors, a mixture of solid lubricant with a liquid mineral gear oil (MVP) or with other oils of the OKB type is used.

For instance, a mixture containing 90% MVP (GOST 1805-51) or OKB-122-16 oil and 10% of the TsIATIM-202 grease Technical Specifications [TU] 517-54 is used, which can be mixed in the plans manufacturing gyromotors.

Solid lubricants are supplied in aluminum tubes containing 50-100 g or, if so stipulated by the user, in tin cans weighing 1 kg or less. A rating plate is supplied with the lubricant, stating the real values of the properties prescribed by the technical specifications or by GOST.

Manuscript Page No.	[Footnotes]
264	The imbalance is measured in gf-cm. It is customary to use the dimensions gf-cm². – Editor.

Manuscript Page No.	[List of Transliterated Symbols]
214	КБ = KB = kontrol'nyy blok = control block
214	В = V = vypryamitel' = rectifier
214	БС = BS = [batareya, sukhaya = dry cell]
214	П = P = pereklyuchatel' = commutator
214	ЭМ = EM = elektromagnit = electromagnet
216	б = b = begovaya dorozhka = race
219	пф (*пф*) = pf = pikofarad = picofarad, μμf
219	мкф (*мкф*) = mkf = mikrofarad = microfarad, μf
219	ком = kom = kiloom = kiloohms
219	Мгц (*Мгц*) = Mgts = megagerts = megacycles
219	Мом = Mom = megom = megohms
219	С дат. (*С дат.*) = S dat. = from transducer (transmitting unit)
219	6С5 = 6S5 [tube designation]
219	6Х6 = 6Kh6
219	6К4 = 6K4
219	6Л7 = 6L7
219	5Ц4 = 5Ts4
219	мгн = mgn = milligenri = millihenries
219	Др = Dr = drossel' = choke
219	220.~ (220.~) = 220v AC
219	6Е5 = 6Ye5
220	мо = mo = mo = mhos
220	мк = mk = mikron = micron (μ)
221	вых = vykh = vykhodnoy = output
221	б = b = beskontaktnyy yemkostnyy preobrazovatel' = contactless capacitive transducer

227 у = u = uravnoveshivayushchiy = counterbalancing

227 р = r = rotor = rotor

229 макс = maks = maksimal'nyy = maximum

229 мин = min = minimal'nyy = minimum

229 д (∂) = d = dobavochnyy = additional

229 к = k = korrektirovochnyy = correcting

230 п = p = probnyy = test, trial

240 р = r = rezonans = resonance

243 ус = us = usilitel' = amplifier

250 ГОСТ = GOST = Gosudarstvennyy obshchesoyuznyy standart = = All-Union State Standard

260 ЦИАТИМ = TsIATIM = Tsentral'nyy nauchno-issledovatel'skiy institut aviatsionnykh topliv i masel = Central Scientific Research Institute for Aviation Fuels and Oils

275 ТУ = TU = tekhnicheskiye usloviya = technical specifications

Chapter 6

ASSEMBLY OF MOTORS FOR GYROSCOPES

§68. ORGANIZATION OF ASSEMBLY

Mass-produced gyroscope motors are usually assembled in individual departments in plans producing their component parts while serial or single units are assembled in special shops.

In the case of unit production, manufacture of the same gyroscope motor is not repeated. Production of the main components and assembly of the motors take place in the same, usually experimental, workshop without a strictly fixed technological process and with wide use of universal equipment and instruments and highly skilled workers. In assembling the various parts and units of the motors they may be fitted up in situ and taken to the finished stage.

In serial production, gyroscope motors are produced in separate batches or series repeated monthly or more often. The components are produced in the main or universal machines arranged to correspond with the sequence of the technological process of machining the main components. The tuned machines are fitted with special or group devices. For machining the other components or executing other operations the machines are set up again; machining strictly conforms to a specified technological process.

In serial production the components are manufactured in accordance with the tolerances laid down in the drawings and the specifications. Slight adjustments are allowed during assembly. The assembly operations are carried out by several operatives in different skill

categories. The motors are assembled in serial production by the method of matching up (selective assembly) or by adjustment. In selective assembly the gyroscope motor components are matched so as to ensure the requisite fit or size. Usually, matching is done in pairs. This method consists in matching to one of the components from an arbitrary number of pairs another giving the required fit and size. Assembly of some gyroscope motor units is by the group method of matching consisting in preliminary division of the components into several groups by size so that any pairs of the corresponding groups may be assembled without fitting.

In serial production of gyroscope motors assembly with compensators or by the adjustment method is widely applied. Assembly by this method makes it possible to obtain the specified accuracy of the unit or the gyroscope motor by changing the size of one of the links already assembled. The gyroscope motor components and units are machined with tolerances set by universal equipment. Change in the size of the compensating link is by adjustment, i.e., by moving one of the components (or units) by the value of compensation or by introducing special disks (spacing disks).

The fixed components introduced into the dimensional chain are called fixed compensators; the moving ones mobile compensators. With use of mobile compensators the accuracy achieved on assembly may be restored by periodic adjustment.

The advantages of selective assembly and assembly with compensators are that they permit wider tolerances in manufacturing the components and at the same time fits of high accuracy. This is particularly important for units which change in size under the influence of temperature and elastic deformations.

In mass production of gyroscope motors one operation is carried

out at each workplace. The time of each operation must be in accord with the tempo adopted. The technological process is worked out in de tail for each operation. The equipment is specially selected or is fitted with highly productive devices and laid out strictly according to the sequence of the technological process. In mass production gyroscope motors are assembled by the method of full interchangeability with use of compensators or by the method of incomplete (partial) interchangeability. In the latter case the specified accuracy of the interlocking elements is achieved not for all but only for some of the uniform dimensional chains.

Gyroscope motors may be assembled with or without division of the assembly operations.

In the latter case the gyroscope motor is assembled from start to finish by one operative but this has the following drawbacks: a) work requiring different skills cannot be broken down; b) the process takes a long time; c) a considerable number of special instruments are required. Assembly without dividing up the technological process is characteristic of unit production and is also sometimes employed in small serial production.

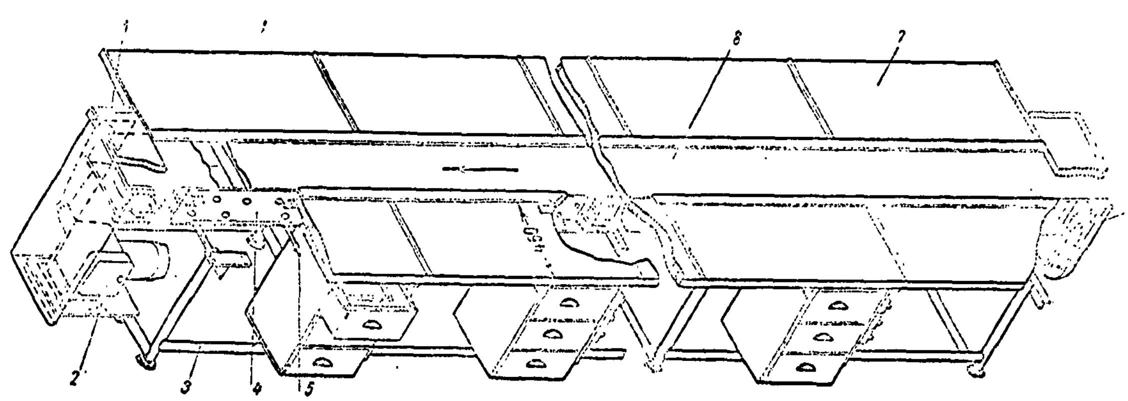


Fig. 110. Layout of belt conveyor with arrangement of workplaces along its length. 1) Driving section; 2) reduction gear with electric motor; 3) frame of base; 4) operating section; 5) air pipe; 6) tightening sec-

tion; 7) workplace; 8) soft belt.

A variant of assembly without division into independent operations is assembly of gyroscope motors by a team of assemblers widely applied in serial production. The technological process must be so arranged that the various operations in assembling the units and gyroscope motor itself are performed by different operatives taking into account their skills. In the team each operative is responsible for certain operations so that the members of the team specialize leading to higher productivity and improved quality.

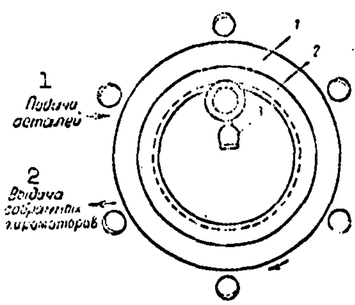


Fig. 111. Layout of circular conveyor. 1) Intake of parts; 2) delivery of assembled motors.

The assembly process may also be broken down into simple individual operations. At first the units are assembled and then the gyroscope itself. The units may be assembled in parallel, each operation being accomplished with suitable devices and instruments increasing productivity and making the process more economical.

If the units and the gyroscope motors are assembled by division of operations each assembler must be assigned one or a few operations necessitating little labor. The units and gyroscope motors to be assembled must pass successively from one operative to the next. Such assembly of gyroscope motors is usually done on a flow line. For divided assembly operations the volume of work and equipment must be such that the time spent on the different operations matches the tempo adopted.

To convey the components and units from one worker to the next and ensure the set speed of the flow line, use is made of belt or plate conveyors.

Figure 110 illustrates the layout of the rubberized cloth con-

veyor belt which can carry items weighing up to 6 kg. It is driven by an electric motor with reduction gear turning a driving drum. The belt is fastened to the end drums; its tension may be adjusted with a screw device. The belt is supported by rollers placed a definite distance apart. The position of the operatives along the belt may be either in parallel or perpendicular.

For output of low numbers of gyroscope motors assembled by the team method, a circular conveyor may be employed moving only in the horizontal plane.

Figure 111 shows the layout of the circular conveyor consisting of a fixed table 1 on which the work is carried out and also table 2 which conveys the gyroscope motors and their units. The only difference between the tables is that table 2 is turned by drive 3 through reduction gear.

§69. REQUIREMENTS FOR ASSEMBLY AREA AND ORGANIZATION OF THE POSITIONS OF THE OPERATIVES

The assembly area, the inspection point and each individual workplace must be thoroughly clean for assembly and inspection of gyroscope motors. Therefore, in all departments where the units and components are manufactured, especially in the assembly shops, measures must be taken to ensure proper cleanliness.

The assembly area and the adjustment-inspection points must be dry, bright, clean and unencumbered. Oil paint is used for the walls and the ceiling, varnished to make washing down easier. The floor must be covered with linoleum. The corners between adjacent walls and especially between the walls and floor must be rounded and painted in bright colors. In order to prevent accumulation of dust there must be nothing superfluous in the assembly area and adjustment-inspection rooms. The assembly rooms must be tidied regularly not only after

work, but in the breaks during the working day. The rooms should be cleaned with vacuum cleaners and the floors rubbed over with a damp rag.

The balancing department must be separated from the assembly department and the fitting out department from the adjustment-inspection point by blank walls.

To prevent dust getting into the assembly rooms from outside or from other rooms, filtered air should be fed into the assembly rooms, producing in the room a slight positive pressure. Such ventilation almost entirely prevents entry into the assembly room of dust-laden air from the corridors, from the street through the window gaps and from the rooms of the other shops. The air in the assembly room constantly kept under low pressure passes out of the room through the gaps impeding the entry of dust-laden air via these gaps. The temperature of the incoming air is kept constant with an air temperature regulator. In winter the regulator warms the incoming air to the required temperature and in summer cools it.

In order to obtain uniform conditions, which is very important

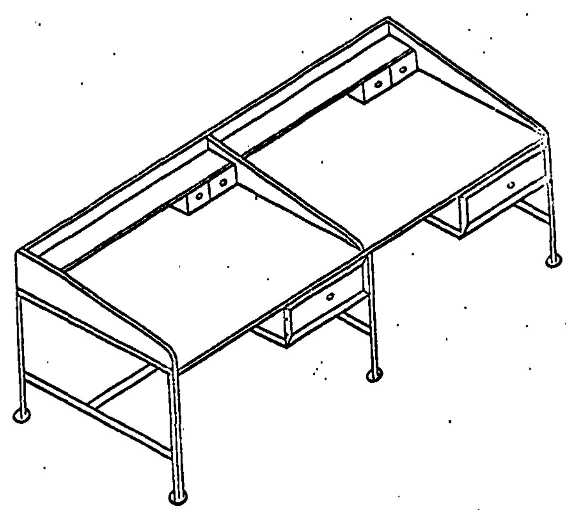


Fig. 112. Bench for two assembly workers.

for ensuring the fit, clearances, resistance and other parameters of gyroscope motors and their unit parts, it is desirable for assembly and inspection to keep the room temperature and humidity constant. Regardless of the weather outside, the necessary temperature and atmospheric humidity within the room are set by special air conditioning plant which in the summer cools and moistens the air fed into the room and in the winter heats and dries it.

The refrigerating machines used for the air condition plant operate with a cooling agent — ammonia or Freon. Central air conditioning chambers may be installed with spray sections or Raschig rings ensuring the necessary temperature and humidity of all rooms in which the components, units and gyroscope motors are manufactured, assembled and adjusted.

As well as apparatus with central chambers, there are devices with local chambers for dry cooling the air (with ribbed pipes through which cooled water is admitted). Usually, the apparatus is fitted with automatic control instruments. The air supplied to the workplaces in the shop from the plant compressor must be clean and dry so that it must be additionally filtered through a dehydrating agent — silica gel.

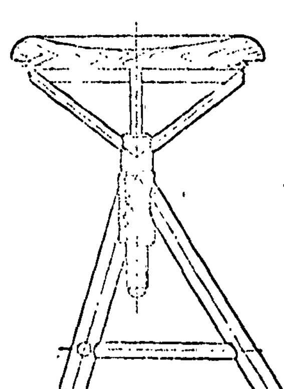


Fig. 113. Seat.

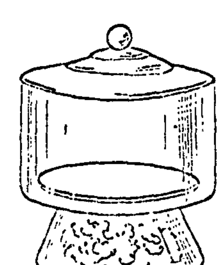


Fig. 114. Glass desiccator.

The assembly room and inspection point must be shielded against direct sunlight. Linen awn-

ings must be hung on the outside of the windows during summer and white batiste blinds on the inside. There should be a damp door mat on the floor at the entrace to the assembly room and inspection point. The assemblers and servicing staff of the assembly shops and inspection point must work in white overalls and caps and wear light sport shoes.

The size of each workplace is 1.2 x 0.8 m. A bench for two assemblers must be regarded as the most practical. Figure 112 shows a bench for two assemblers used for the team method of work and Fig. 110 the benches attached to the conveyor.

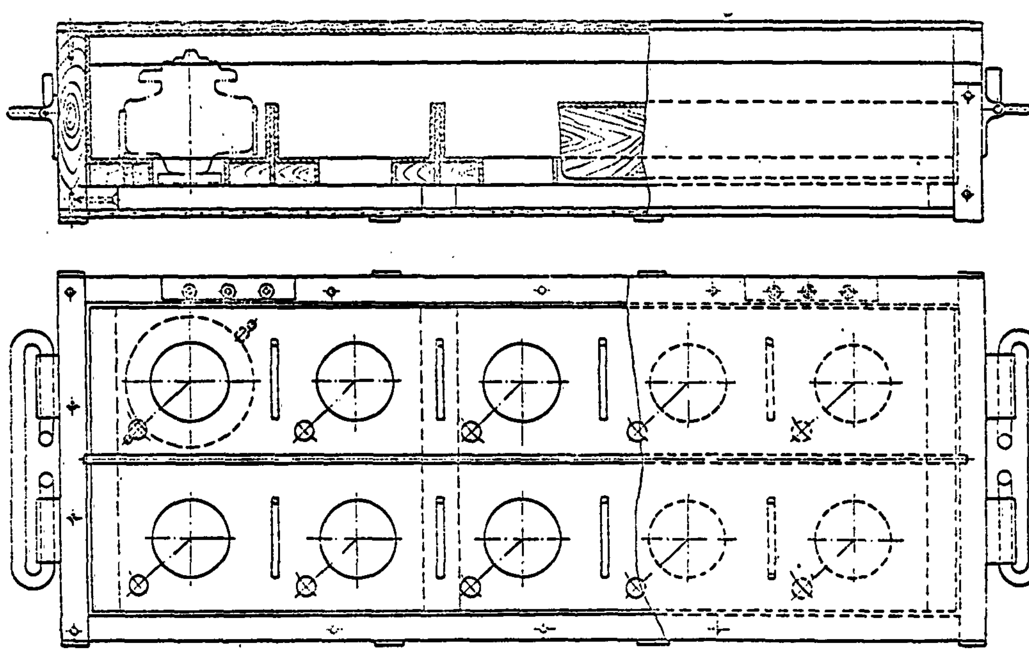


Fig. 115. Packaging for transports of gyroscope motors.

The benches in the assembly room must be so arranged that daylight falls either behind or to the left of the assembler. Each workplace must have a stand with a table lamp for local illumination. The position of the assembler must be such that during work he has no need to bend or stretch. The benches should normally be 850-900 mm high.

They should be covered with linoleum. A seat must be available at each workplace. One of the seats adopted in assembly shops is shown in Fig. 113. It can be adjusted to suit the height of the worker. The seat has a crosspiece joining the legs on which the assembly worker may place his feet during work.

The bench is a table at the sides of which there are shelves for laying out the instruments, components, units and assembled gyroscope motors during work. The bench must be fitted with drawers with compartments to take the different instruments. The instruments are best stored by making shaped grooves in the drawers to take the instruments and prevent their touching. Small instruments (drills, rat-tail files) should be kept in separate wells. Each workplace must have a rubber mat, a set of three glasses or porcelain baths and a glass desiccator (Fig. 114) with silica gel in which to put the gyroscope motor components and units.

During assembly the instruments and components should be so laid out on the bench that the movements involved in the operations are short and do not tire.

It is particularly important to keep the workplace and room clean during assembly of fast-running gyroscope motors. However carefully the room is kept tidy and the air purified, the air is bound to contain microscopic particles of metallic and abrasive dusts which penetrating into the lubrication of the fast-turning ball bearings may increase the roughness of the surface of the races which in turn leads to disturbance in balancing and premature destruction of the ball bearings. To ensure cleanliness the gyroscope motors must be assembled under transparent hoods supplied with purified and pressurized air. The assemblers carry out the final assembly of the gyroscope motors through holes in the sides of the hood.

At the workplaces there must be appliances for keeping them tidy and waste paper baskets. The assemblers must wash their hands from time to time.

All the parts and units and also the gyroscope motors themselves must be conveyed in special packings (Fig. 115) in the form of closed dry boxes with cells sealed with soft material.

In assembly of the gyroscope motors and their units on the conveyor, the work benches are placed on both sides of the moving belt. The same measures applied in order to keep the workplace and the room itself clean in assembly at the benches have to be observed for conveyor assembly.

On the proper layout of the operatives' workplaces depend the labor productivity and the quality of the gyroscope motor assembly. The benches must be correctly positioned and of suitable design. Conditions must be such that the assembler can perform rational work movements and steps must be taken to ensure the proper layout of instruments, devices, parts and auxiliary material on the job. The lighting must be adequate, efficient and not tire the eyes. The work schedule must be properly organized.

§70. PLANNING THE TECHNOLOGICAL PROCESS OF ASSEMBLY

Planning the technological process of assembling gyroscope motors, like the whole process of gyroscope motor manufacture, forms the main part of the preparative work for production. Consequently, in the planning of the technological process it is necessary to determine the whole range of operations. Planning the technological process of assembly, like the whole technological process of gyroscope motor manufacture, may take two lines: planning for new plant and shops or planning for assembly of new types in an existing plant.

In the first kind of planning the most rational processes for ma-

chining the parts and assembling the motors have to be adopted. For the second type the possibility of equipping existing plants has to be considered. Moreover, on the basis of technical and economic calculations it is also necessary to introduce into production the latest methods of machining and assembling the parts taking into account the possibilities and need for procuring and making the necessary equipment.

The main object in planning the technological process of gyroscope motor assembly is to achieve high-quality motors complying with the specifications, at the least cost and with the highest productivity.

The initial requisites for planning are drawings, specifications, the size of the production assignment and, as stated above, whether production will be in new or existing plants.

Usually, in planning the technological process of serial production there are drawings and specifications checked in preparing the models and these models are available considerably facilitating the technological development work. On the basis of the drawings and the models the make-up of the product is fixed in the form of an assembly diagram which determines the interconnections of the parts and units of the motor. The assembly diagram makes it possible to map out the sequence of the assembly operations.

Figure 116 shows the assembly diagram for a gyroscope motor in which the parts and units are given in the form of rectangles and the lines between them show the sequence of their attachment during assembly of the motor. The diagram is constructed in such a way that the preceding operations do not hamper later ones. The parts and units must be joined without dismantling units previously assembled.

The technological process of assembly should be broken down in

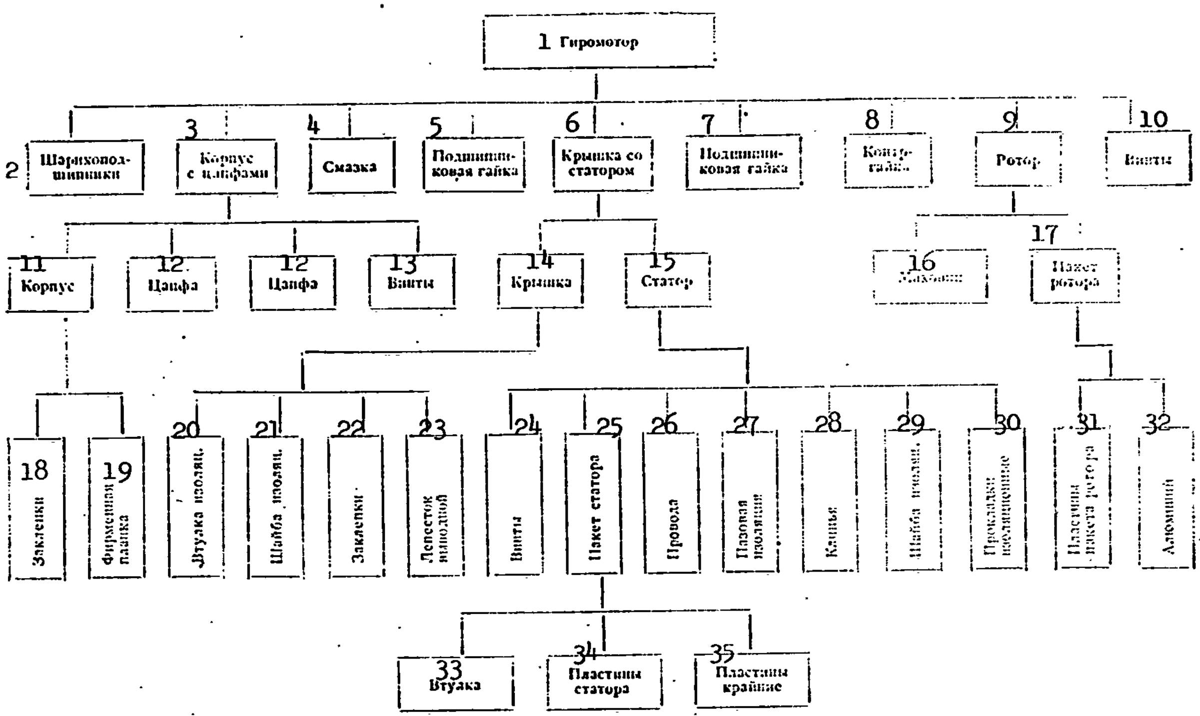


Fig. 116. Arrangement for assembling gyroscope motor illustrated in Fig. 4a. 1) Gyroscope motor; 2) ball bearings; 3) casing with journals; 4) lubrication; 5) bearing nut; 6) cover with stator; 7) bearing nut; 8) locknut; 9) rotor; 10) screws; 11) casing; 12) journal; 13) screws; 14) cover; 15) stator; 16) flywheel; 17) core rotor packet; 18) rivets; 19) manufacturer's plate; 20) insulating bush; 21) insulating washer; 22) rivets; 23) output lobe; 24) screws; 25) stator lamination; 26) wires; 27) groove insulation; 28) wedges; 29) insulating washer; 30) insulating gaskets; 31) plates of rotor packets core; 32) aluminum; 33) bush; 34) stator plates; 35) end plates.

such a manner that the units can be separately assembled and can be passed on for completion. The process of assembly must also be broken down into the simplest operations; the quality of assembly should be verified in the course of the operations. The technological process of gyroscope motor assembly is set out in technological charts. In some factories it is worked out on operation-instruction charts; such a chart is shown in Table 6.

The charts of the technological process of assembly are filled in for the separate units and over-all assembly of the gyroscope motors; the chart indicates the number of the operation, gives a concise but exhaustive description of the operations, equipment, and the devices, the work tools and measuring instruments, the class of work and the time norm necessary for performing a particular operation.

The technological charts must also indicate the permissible temperature and humidity for particularly important operations. Execution of all operations and conveyance in strict conformity with the direction on the technological process of assembly worked out and tested in production conditions on several batches is a necessary condition for obtaining high-quality gyroscope motors operating reliably in gyroscopic instruments.

§71. JOINTS USED IN ASSEMBLY

The parts and units of gyroscope motors are joined either in a fixed and permanent manner, for example, by soldering, shrink-fitting and flaring, or movably. The latter joints may be pull-apart, threaded or permanent-mobile, as, for example, ball bearings.

The parts and units forming permanent joints cannot be taken apart without damage; pull-apart joints may be taken apart without damage to the connecting and coupling parts and units.

Permanent Joints

Examples of permanent joints used in gyroscope motors are attachment of the manufacturers' plates to the casing and the leadout ends of the stator winding to the output lobes. In some gyroscope motor designs the output ends are bonded to the surface of the frame after soldering.

Solid rivets are used to fix the manufacturer's plates to the frames while the output lobes are fixed to the covers with hollow rivets. To obtain a high-quality riveted joint the length of the rivet and the diameter of the hole must be of the right size. The length of the rivet shank must be such that the material of the rivet suffices to form the holding head and to fill the space between the rivet shank and the walls of the hole. The protruding part of the shank must be 1.3-1.6 of its diameter. The strength of the riveted joint also depends on the size and shape of the rivet point. Rivets for fixing the manufacturer's plate have on the side of the casing a countersunk head which enters the hole together with the inner countersink.

Riveting is done with a device (Fig. 117) which is inserted into a hole in the frame. The rivets are inserted into the holes from the

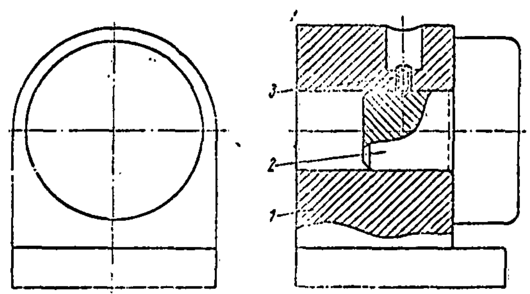


Fig. 117. Device for fixing manufacturer's plate to frame. 1) Base; 2) mandrel; 3) screw.

inner side of the frame; the manufacturer's plate is slipped on to the projecting ends and is pressed to the frame. The rivet heads are

clinched in such a way that they do not protrude into the cavity of the frame. The rivet surplus is bitten off allowing for the head and is provisionally shaped. Then, the rivet head is finally shaped with a die, the depression in which has the required shape. Preliminary clinching and snapping of the head must be done carefully with a hammer weighing 100 g so as not to deform the finally machined frame.

The contact lobes in the cover are assembled by joining with a tubular rivet as follows: after drying by a special method, the insulating carbolite bushing and the pertinax insulating bush, the contact lobe and the tubular rivet are washed in benzine and dried in air until free of the odor of benzine. Then the bushing is inserted into the hole on the left side of the cover and fixed; the bush and lobe are slipped on to the bushing. The tubular rivet is inserted within the bushing, a brass washer slipped on it, a punch inserted into the rivet hole and then, at first, it is expanded in preliminary form and then with a second punch in final form.

The leadout ends of the stator winding are connected to the lobes by a permanent, soldered joint. The soldering is with POS-61 tin solder; nonacid flux is used, made from colophony and alcohol.

In some gyroscope motor types the stators are fixed to the covers by permanent joints for which purpose there are special bushings in the covers which after the stators have been fixed on them are expanded (Fig. 7b and 7c).

Nonpermanent Threaded Joints

In gyroscope motors as in other instruments nonpermanent threaded joints have been used most extensively. The reason is to be found in the simplicity and reliability of such joints, ease of controlling the tightness, and also the possibility of dismantling and reassembling the joint without replacing the parts.

The threaded joints of gyroscope motors ensure the proper positioning of the coupling units and the relative immobility of the parts to be joined, controlling the relative positions of the parts and the relative movement of the parts.

The principal threaded joints in gyroscope motors are screws and nuts with cylindrical, metric thread with a profile angle of 60°. The screws are produced on automatic lathes with the thread cut by a thread-cutting machine or for relatively unimportant joints by heading with subsequent rolling of the thread.

The threads on the screws are not always cut accurately coaxial with the cylindrical surface of the screw and therefore do not ensure accurate fixing of the parts. The accuracy of joining the parts without fixing locks is determined by the clearance between the screw and the surface of the through hole, the size of which depends on the screw diameter.

The main element determining the fit of the threaded joint is the mean diameter. In gyroscope motors, screws with a sliding fit are employed; the screw and nut must be screwed tightly over the entire threaded part. An incorrect angle of the thread means that the turns are united not over the entire surface although during turning the thread may appear to be tight. If there is an error of the thread pitch of the screw or nut then for 2-3 threads screwing is easy but then becomes more and more difficult. Too loose a fit of the screw results from a reduced working surface of the engaging turns; the thread on screwing up is overloaded, mashed and sometimes even broken. During assembly of gyroscope motors it is important to make the threaded joint with the required clearance ensuring reliable attachment, in particular of the cover to the frame. Jolting, vibrations and knocks must not affect the necessary tension of the ball bearings.

which largely determines the accuracy of work of the motor. On assembly of detachable joints in gyroscope motors care should be taken to see that each screw or nut is smoothly screwed in. If any defective screwing is observed, the screw or nut must be replaced.

Fixing threaded joints in gyroscope motors is carried out with preliminary tightening essential for prolonging the life of the joints and also affecting, as will be shown later, the quality of the gyroscope motor. Preliminary tightening is such that elastic deformations of the parts for assembly have a definite value in the system of work fixed.

§72. ASSEMBLY OF COVER WITH STATOR

The stator is attached with winding to the cover of the gyroscope motor by two main methods.

In the first method fixing is done by pressing the stator bush with the hole onto the bush cast with the cover. Sometimes for this purpose on casting into the cover the stainless steel bush is reinforced (see Fig. 7c).

In the design under study the stator is fixed by an undetachable connection. Machining the outer surface of the bush for seating the stator and the holes of the bush is done from one setting on machining the lock of the cover for fitting into the casing. On assembly of the cover with the stator the latter is placed by hand with the hole of the bush on the external diameter of the bush of the cover. Then with an indicator with a graduation of 0.001 mm the clearance of the lamination relative to the lock of the cover is checked. Checking takes place in centers on a mandrel smoothly passing into the hole of the bush of the cover. If the clearance of the stator does not exceed the tolerance figure the stator is pressed down by hand onto the bush. Then the stator and cover are removed from the mandrel and without

moving the stator from position, the bush edges are first flared roughly and then finally, by turning on a drilling machine. After expansion the stator must not be perforated at the bush on the edges of which there must be no cracks and hollows in the metal in the hole of the bush. Finally, the play of the external surface of the stator is checked and also the cylindrical surface and end of the lock of the cover.

Besides the play and quality of attachment of the stator on the bush, a check is made on the resistance of the insulation, the absence of breaks and short-circuited turns in the stator winding. The check is made by measuring the phase currents, for which purpose the stator with winding is introduced into a cylinder made of Armco iron of size corresponding to the length and external diameter of the stator to be measured with some allowance. Then the three ends of the winding of the stator are connected to the high-frequency AC line and an ampere meter switched into each phase determines the phase currents on turning the cylinder through 360°. The measured phase currents may differ from their set mean value by a permissible value.

With the second method the stator is fixed to the cover with screws (Fig. 118). The layer of lubricant protecting the stator bush against corrosion is removed, the threaded apertures are calibrated with a tapping drill thereby freeing the thread of contamination, the face is washed with a toothbrush and the threaded holes of the bush with benzine. The fitting surface of the cover is also washed with benzine and dried in air until it no longer smells of benzine.

The cover is placed over the fitting surface of the stator bush and fitted tightly by hand. Then the output ends of the stator winding are soldered to the output lobes; the output ends are stretched and placed along the radius of the cover, aligning the holes for the

screws of the cover with the holes in the stator bush. At first the screws are screwed into the stator bush; before this the threaded surface is painted with nitro enamel which prevents the screws working loose. Then, the screws are gradually tightened. The screws should be

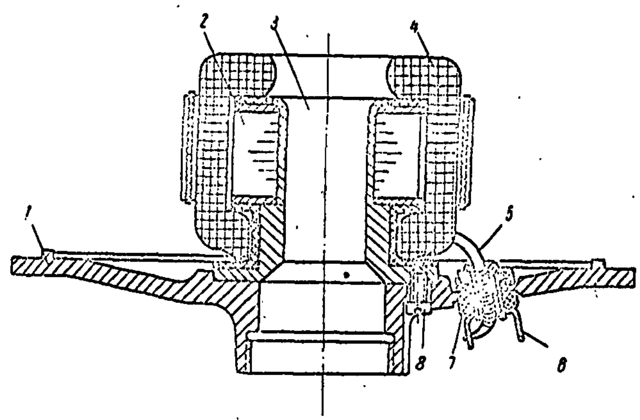


Fig. 118. Fixing stator to cover. 1) Cover; 2) stator core packet; 3) bush; 4) winding; 5) output ends of winding; 6) output lobe; 7) insulating bush; 8) screw.

tightened crisscross and care should be taken not to overtighten them as the slots or threads may strip. After tightening the screws, they are locked, painting the heads with nitro lacquer.

The permissible value of play of the external surface of the stator packet relative to the lock of the cover for the gyroscope motor frame is ensured by accurate boring under the shoulder of the bush in the cover and accurate polishing of the outer surface and face of the shoulder of the stator bush.

After assembly of the stator with the cover a check is made on the quality of the connection, the insulation resistance, the absence of breaks and short-circuited turns in the stator winding and the unit is sent for final assembly.

§73. FINAL ASSEMBLY

Packed in a special box, the units going for final assembly of the

gyromotor include the casing with its journals protected and cover attached with fixed stator and winding; the dynamically balanced rotor with the inner rings slipped onto the axle journals and the other parts (separator, balls and outer ring) wrapped in nonfibrous paper; the ball bearing covers with nuts; the fixing screws, etc. The rotors and ball bearings, after removal of the lubricant, cannot be kept in air for more than two hours. They must then be kept in a desiccator with blue or blue-green silica gel.

Final assembly of the gyroscope motor is done in two stages – preliminary and terminal.

§74. THE PRELIMINARY ASSEMBLY

The preliminary assembly of a gyromotor consists in matching of the parts and subassemblies that have been completed for the assem-

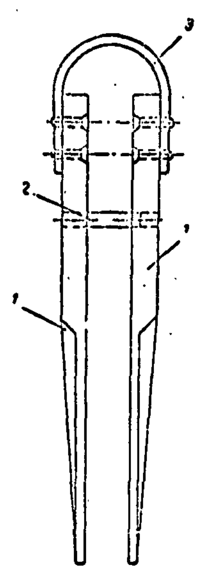


Fig. 119. Forceps. 1) Leg of organic glass; 2) pin; 3) spring.

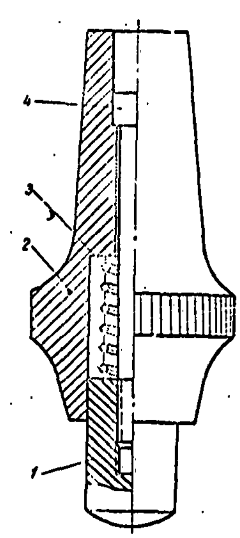


Fig. 120. Dosing apparatus for grease. 1) Head; 2) case; 3) spring; 4) screw.

bly of a certain number of gyromotors. After the selection of parts and units the numbers are noted, the gyromotors are assembled and sub-

jected to preliminary test by which all defects are exposed, and the ball bearings are run in.

The assembly is started by taking the cover off the body and tapping the threaded holes in it for the fastening screws. The ball-bearing covers are selected by turning them in body and cover. After tapping, the screws, threaded holes in the body, the nuts and ball-bearing covers are washed with gasoline, the inner surface of the body is rubbed, and the parts are air-dried until the smell of benzine has completely vanished. The fitting surfaces and threads are inspected under a magnifying glass with 6-fold magnification. If indentations, cavities, or disruptions in the screw threads or other defects are found, the bodies and covers are rejected. The rotor and ball bearings are taken out of the desiccator, and the inner rings of the ball bearings and the nuts fixing them are cleaned with a hair brush in pure aviation gasoline. The rotor is air-dried until the gasoline is removed, it is rubbed inside and outside with a batiste cloth, and the inner ring on the ball bearing on the rotor is inspected. There must be no cracks, deformation flat spots or other defects. The surface roughness must not exceed the permissible value. The inspection is made by using a magnifying glass with 6-fold magnification.

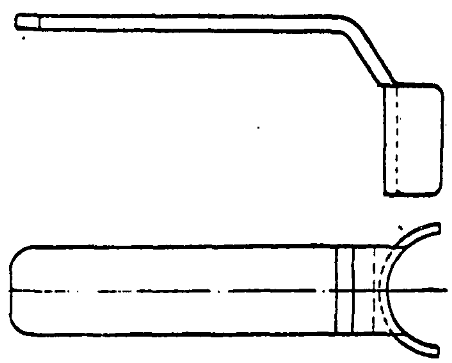


Fig. 121. Organic glass holder for putting the balls into the snap-ring.

The rotor is placed with the open side up on a support previously rubbed clean (see Fig. 105) and the stator with the cover is inserted. The outer ring and the snap-ring of the ball bearing are taken out of paper and immersed in a gasoline bath. The parts are washed in three

basins made of glass or porcelain, covered with glass plates, and filled with "Kalosha" or B-70 gasoline. The parts are held with forceps with special tips (see Fig. 119). The outer rings and the snap-ring are air-dried until the gasoline has evaporated. In order to speed up drying, the parts are blasted with air from rubber syringes. After washing and drying, the outer rings and the snap-ring are carefully inspected under a magnifying glass with 6-fold magnification, to make sure that there are no cracks, scaling of metal on the race, traces of corrosion and other damage. The balls are washed in special nets (see Fig. 106) by immersing them 5 to 6 times consecutively in the three gasoline baths. After washing, the parts are dried with air from a syringe, rubbed with lint-free paper, and each ball is inspected under a magnifying glass at 6-fold magnification, to ensure that deformation flatspots, corrosion and other defects are absent.

If there are any defects, even on one ball only, the ball bearing is rejected and the rotor is balanced again with another ball bearing.

The washed and dried parts of the ball bearing are placed on a cloth of varnished fabric, on which 30-40 mg of TsIATIM-202 grease have been pressed previously by a special dosing apparatus (Fig. 120), and the whole surface of all parts of the ball bearing are carefully covered with it.

The second ball bearing is treated similarly. One must keep in mind the fact, stated above, that radial-thrust ball bearings are delivered with noninterchangeable rings and balls. For this reason, the parts of the ball bearings cannot be allowed to become mixed up during assembly; e.g., the outer or inner rings or balls of one ball bearing are not allowed to be interchanged with rings or balls on another.

Through the hole in the cover for the ball bearing, the greased snap-ring with the balls is placed onto the inner ring of the ball

bearing, which is mounted and fixed by a nut before balancing the rotor, and, using a special holder (Fig. 121), the balls are placed on the race of the inner ring. Then the outer ring is put into the seat for the ball bearing in the cover, drawing the ring tight by turning a special nut; after the ring is tightened, the nut is unscrewed.

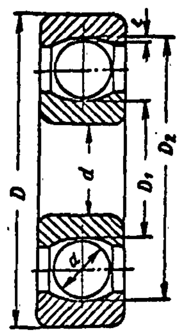


Fig. 122. Schematic representation of gaps in a ball bearing.

When the outer ring is mounted in the seat of the cover, it is picked up so that it can be inserted without skewing by pressing it with the thumb of the right hand. If the outer ring is inserted askew, the race is displaced and the moving balls acquire variable speeds causing them to exert an additional pressure on the snap-ring, which may cause its destruction. The outer ring should not be turned in the cup.

The character of stress distribution inside the ball bearing is different for the inner and outer ring. For this reason, as a rule, a different fit is required for the ball-bearing rings on the neck of the axle and in the seat of the body or cover. As mentioned in Chapter 5, the fit of the ball bearing on the neck is accomplished according to the hole system, and in the seat of the body and cover according to the shaft system.

If the ball bearing is mounted on the neck or in the seat of the body or the cover very tightly, the rings of the ball bearing are deformed, the diameter of the inner ring is increased, and the diameter of the outer one reduced. Consequently, the diametral gap (Fig. 122) between the races and the balls is reduced from

$$e = D_2 - (D_1 + 2d_{sh})$$

to

$$e_1 = D_2 - (D_1 + 2d_{ш})$$

in the case where the ball bearing is pressed on the neck, and to

$$e_1' = D_2' - \left(D_1' + 2d_{ш}\right)$$

in the case where the ball bearing is pressed into the seat of the body or cover. Here D_1' is the diameter of the race of the inner ring before and after pressing it onto the neck; D_2' is the diameter of the races of the outer ring before and after pressing it into the cup.

Thus, if the ball bearing is pressed in tightly, the radial gap of the ball bearing is reduced by

$$e - e_1 = D_1' - D_1 = \Delta D_1.$$

The reduction of the gap can be approximately calculated using the formula

$$\Delta D_1 = \frac{0{,}8hdK}{d + 5{,}85\,(1 - K^2)},$$

where h is the theoretical clearance when the ball bearing is pressed onto the shaft; $K = d/d_p$ is a coefficient varying from 0.9 to 0.7 depending on the type of ball bearing; d is the inner diameter of the ball bearing.

It is assumed that the change in diameter of the races of the inner rings is about 0.7 and of the outer ring — 0.8 of the actual clearance.

Thus, if both rings of a ball bearing are fitted with corresponding tightness, in consequence of the increase in the diameter of the inner ring and the reduction in the diameter of the outer ring the ball may even be pinched.

When the gyromotors are used, the rings become warm. The inner ring becomes a little warmer than the outer one. The temperature difference between the rings in radial-thrust ball bearings does not exceed 10°, as was found experimentally. The variation of temperature

also affects the size of the radial gap of the ball bearing. The reduction of gap width by a change in temperature may be calculated using the formula given in Chapter 4.

Fitting both rings with some gap is not admissible as this makes it impossible to achieve the necessary precision of alignment and balance. The inner and outer rings of the ball bearing, under the action of a constant load, do not work under the same conditions. On the inner ring, which rotates with the rotors, the races wear uniformly. In the immovable outer ring which is located in the seat of the body or the cover, in case of an imbalance of the rotor, the load acts always on one small part of the race and gradually destroys it. In order to reduce wear it is necessary to fit the immovable ring in the seat of the frame and cover so that the ring has an opportunity to turn slightly.

After inserting the ball bearing into the seat of the cover, the recess in the bearing nut is filled with TsIATIM-202 grease up to half its volume, distributing the grease along the walls and lightly greasing the entering part of the thread in the nut. If the grease is supplied in tubes, its upper layer of about 3-4 mm thickness cannot be used to grease ball bearings because there may be metallic particles in this layer which appear when the tube is pressed.

After this the nut with the grease is turned tight by means of a key (Fig. 123) into the outer ring of the ball bearing. The rotor and the cover are turned over on the support. The snap-ring with the balls is mounted, setting them right with a special holder into the race of the inner ring which is put on the neck of the rotor, from the side of the body. The outer ring of the ball bearing is inserted into the seat of the body by means of a special nut. The body with the inner ring is put on the rotor with the snap-ring and the balls, and the bearing

nut, which has been half filled with TsIATIM-202 grease beforehand, is tightened.

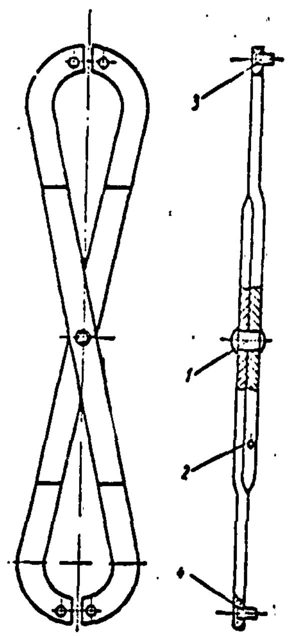


Fig. 123. Special key for turning the bearing nuts. 1) Axle; 2) clamp; 3 and 4) pins.

The gyromotor is turned over on the support with the cover on top; the cover is turned around according to the plan loosening the bearing nut by 2-3 turns. The cover is tightened on the lock of the body, and the bearing nut is tightened again. After this, the cover with the stator is screwed onto the body, at first preliminarily, and then with the necessary tightness. The final tightening is exerted uniformly, screwing up diametrically opposed screws. The bearing nut is screwed tight without using force. Only such screws may be fixed which can be turned tight right to the end without jumping.

After preliminary assembly, the check card on the gyromotor is made out. This gives the serial number of the gyromotor as stamped on the maker's plate, the numbers of the ball bearings, the number of the rotor, the fitting stress of the inner rings and other necessary data. On the card the name of the assembler who has assembled the gyromotor is written. After this he, or some other assembler to whom he turns over the gyromotor, performs the tightness adjustment of the ball bearings.

§75. ADJUSTMENT OF THE AXIAL FREE PLAY

A most important stage, which crowns the mounting of the ball-bearing parts of the gyromotor, is the adjustment of the axial free play of the ball bearings.

Not only does the life of a ball bearing depend on the correct

amount of axial free play, but also the precision of the indications given by the instruments in which the gyromotors are installed. It is known from the theory of the performance of the gyroscope that the frictional moment in the ball bearings of the main supports of the gyromotor affects only the power dissipated in the rotation of the rotor, while the friction in the ball bearing of the suspension gives rise to a precessional moment which reduces the precision of the instrument. A free play in the ball bearings of the suspension is permitted, but in the ball bearings of the gyromotor it needs to be reduced as far as possible. To ensure the precision of gyroscopic instruments it is necessary to have as little friction as possible in suspension ball bearings, but in the gyromotor ball bearings there must be no axial free play. Thus, when gyromotors are assembled with radial-thrust ball bearings, there must be no axial free play – i.e., no displacement of the outer ring of the ball bearing from one position to another in the axial direction and there should be some interference.

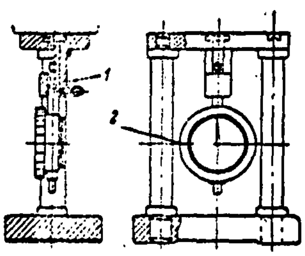


Fig. 124. Device for testing the axial free play. 1) Frame; 2) indicator.

When the value of the axial tightness is established, the variation of linear dimensions of the rotor axle and the body and cover with varying temperature must be taken into account. The value of the tightness should be within limits that provide for normal work and long lifetime of the ball bearing at different temperature. At the same time, variations of temperature should not cause axial free play in the main supports of the gyroscope.

The adjustment of the tightness in gyromotors with radial-thrust ball bearings is effected by a displacement of the outer rings in the seats of the bodies and covers. The axial free play in gyromotors with

projecting rotor axle ends and nondetachable ball bearings are measured in special devices (Fig. 124). The adjustment is performed by adjusting disks or a nut.

In closed-type gyromotors, in which there are no projecting free axle ends, the testing of the value of the axial free play of ball bearings is difficult. Sometimes the test of the axial free play is restricted to a test of the ease of motion of the rotor in the ball bearings, for which purpose the rotor is set in spinning motion, and the free play is determined from the character of its rotation and stopping. If the ball bearings are strongly tightened, the rotor spins for a short time only and stops at once. If there is much free play, the rotor spins easily for a long time and stops gradually. If the tightness is small, the rotor runs smoothly, giving a steady hum; the spinning of the ball bearings of good quality lasts for several minutes, and it stops with a comparatively rapid decrease in speed.

A widely used method of determining the axial free play is the determination of the tightness from the sound which the body of an assembled gyromotor gives when it is tapped.

The determination of interference from the sound is fairly simple, it does not require any instruments, and with sufficient experience it makes it easy to decide whether there is tightness or not; but an exact determination of the value of the interference is impossible. If this method is used, after assembling the gyromotor and tightening the bearing nuts, the inspector taps the bottom of the body lightly with the knuckle of a bent index finger. If there is free play in the ball bearing, the body gives a jarring, rapidly damped sound. If there is axial interference, it will give a pure sound which is gradually damped. The greater the tightness, the purer and more protracted is the sound of the body. There are a number of factors affecting the pu-

rity of the sound emitted by the body which are difficult to take into account. Therefore after the existence of axial tightness has been established by this method using the assembler's experience it needs to be checked. For this purpose, the reliability of the gyromotor at temperatures below zero is tested. The method of testing gyromotors at temperatures below zero is described in Chapter 7. The tightness is in this case determined from the speeding-up time and the value of the steady currents. Such a test does not permit of determining the value of the tightness exactly, but it prevents an overtightening of the ball bearings. If they are overtightened, the currents become larger than is admissible.

The existence of axial free play and overtightening of ball bearings can be determined from the speed of revolution of the rotor, the running-down time and the excess temperature. Thus, if the phase currents are large and the temperature raised, if the rpm of the rotor are low and the running-down time is short, one may say that, if there are no other reasons, in this gyromotor the ball bearings are tightened beyond the permissible measure.

To determine the exact value of the axial tightness in closed-type gyromotors, some devices based on different operational principles have been devised. The most successful of these is a device based on the deformation of the cover, which has been brought about previously by applying loads, which determine the necessary tightness of the ball bearings.

Figure 125 shows one of the devices in which the assembly and the adjustment of axial tightness of ball bearings in closed-type gyromotors are performed. The assembly and adjustment of the axial tightness consists of three procedures: the determination of the rigidity of the cover of the gyromotor and the device itself; pressing

the outer rings of the ball bearings into the permanent supports of the bearing cover ends, and the removal of hidden free plays; adjustment and establishment of the necessary axial tightness of the ball bearings.

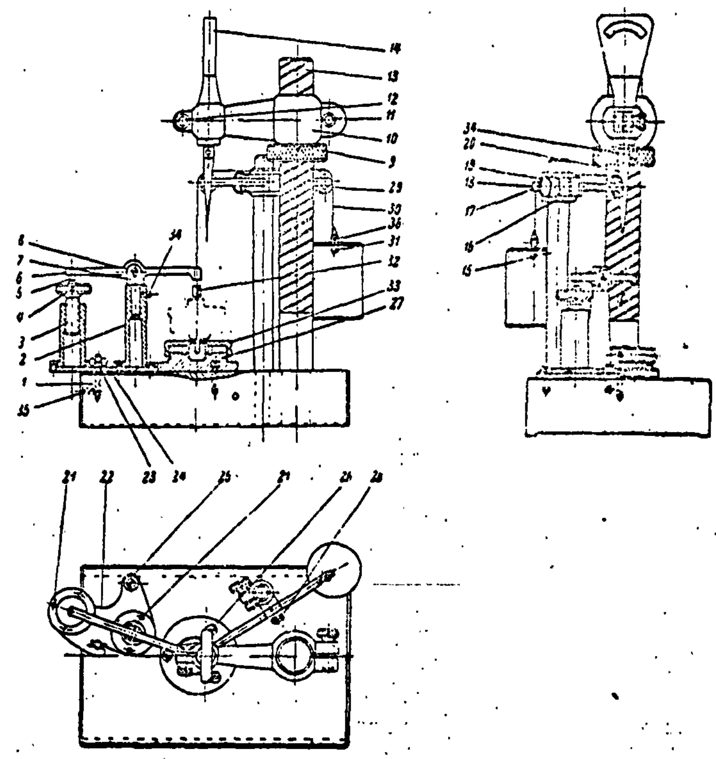


Fig. 125. Device for the establishment of the axial tightness in gyromotors. 1) Platform; 2,3, and 15) pillars; 4) support; 5,18,34,35) pins; 6) lever; 7) head; 8) clinch; 9,32, and 33) nuts; 10) arm; 11, 12,21,26,28) screws; 13) core; 14) straddle gage; 16) collar; 17) shaft; 19) roller; 20) leg; 22) plate; 23) special screw; 24) wing nut; 25) disk; 27) holder; 29) ball bearing; 30) cable; 31) load; 36) eye.

When the necessary tightness has been established, at first the rigidity of the cover and the device itself are determined. For this purpose, the gyromotor is seized in a carefully rubbed draw-in chuck of the device by means of the projecting end of the body and the bearing nut. Then the gyromotor is fixed tightly by turning the nut of the device, without deforming the rear part of the body, into the device

in a vertical position, as shown in the figure. Onto the threaded shaft of the bearing cover, a sleeve is turned with a special nut and a cable; the cable is put onto the roller of the device. The leg of a straddle gage with a scale division of 1 micron, and of previously known measuring stress, is placed on the cover at the point on the radius at about 15 mm, midway between arbitrary disengaging lugs. This point is marked with red or white enamel. In later measurements and adjustments of the axial tightness, the leg of the straddle gage must be placed on the colored point. On the other end of the cable, on a hook, a special weight chosen for each type of gyromotor is suspended (taking into account the measuring pressure of the straddle gage), and the indications of the straddle gage are recorded without and with the load. From the difference between the readings of the straddle gage with and without the load, the deformation (rigidity) of the device and the cover with all thread connections of the given gyromotor is determined. Then, any hidden free plays in the bearing units are removed that had not been discovered during assembly because of the tight fits and misalignment of the outer rings of the ball bearings in the seats of the bodies and covers. When the gyromotor is in operation, in consequence of warming up, these hidden free plays cause an increase of the axial free play in the main supports of the gyromotor. In order to remove them, the bearing nut is, without the locknut, drawn tight with a special key. After this, it is further turned through an additional angle, so that the cover is bent by the additional stress to a straddle gage indication of 10-15 microns. The additional stress completely removes the hidden free play of the ball bearings and tightens the outer ring of the ball bearing to the face of the bearing cover which is screwed to the body. After this, the nut is loosened by 0.5 to 1 turn, so that the cover is pressed with a

stress causing a downward displacement of the cover of 8 to 10 microns (on the reading of the straddle gage) in order to remove any hidden free play from the tight fit and misalignments of the outer ring of the ball bearing, fixed in the seat of the cover. Pressure is exerted on the cover by means of a lever fixed on a pillar of the device, which is V-shaped on one side and supported on the upper part of the cover; on the other side, the lever rests with a pin on a projection of the head of a special screw, turned into a sleeve of the device. If the screw is turned out of the sleeve it exerts pressure on the pin of the lever, and the lever itself presses with its other side on the cover. In this way, by turning the screw, one can produce any desired deformation of the gyromotor cover. One can also exert pressure on the cover with the fingers of one's hand, so deforming the cover by 8-10 microns.

After the free plays have been removed, and one is convinced that the outer rings of the ball bearing are in tight contact with the faces of the bearing covers, the axial tightness of the ball bearings required for the given type of gyromotor is established. When this has been done a sleeve with a special nut and cable is screwed on the threaded shaft of the bearing cover, as was done when the rigidities of the cover and the device were determined. The cable is laid over the blocks of the device; on the other end of the cable, the load required for the given gyromotor is suspended on a hook. When the value of the load is calculated, the measuring pressure of the straddle gage spring must be taken into account, this being 300 gf on the average. The straddle gage leg is put onto the point of the cover which was painted when the rigidity of the cover was determined, and the indications of the straddle gage are read in microns before and after suspending the load. The value of the deformation of the cover in microns

will be equal to the difference of the fixed straddle gage indications and the indications which were read when the rigidity of the device and the cover were determined. The cover will also press on the outer ring of the ball bearing, creating a stress in the axial direction of the ball bearing which is equal to the suspended load.

For the straddle gage indication under the influence of the load, its maximum indication is taken when the load is smoothly lowered. In order to check the correctness of the reading, additional pressure is exerted on the cover by hand and the resulting change in the straddle gage indication is noted when this additional load is removed. If there is a difference of more than 0.5 micron in the straddle gage readings before applying and after removing the additional load, the procedures for establishing the tightness must be repeated.

If the difference between the readings is less than 0.5 micron, the load is taken off the hook, the sleeve with the cable is unscrewed from the threaded shaft of the bearing nut, and the locknut is screwed on. The bearing nut must be fixed on the cover of the gyromotor by the locknut so that the finally established value of the tightness (in microns) does not differ from that required by more than ± 0.5 micron. After tightening the locknut, without taking the gyromotor out of the holder and without taking the straddle gage leg from the cover, pressure is exerted on the cover by hand several times. The straddle gage indications before and after applying this pressure must not differ by more than ± 0.5 micron. Otherwise the tightening to establish axial tightness has to be repeated.

As the linear dimensions of the body and cover vary with a variation of temperature, the establishment of the axial tightness has to be performed at a normal temperature of 20°, or at a temperature stipulated by the technical specifications for the given type of gyromo-

tor. Before the establishment of the axial tightness the gyromotors must be kept in the same room for at least one hour. The temperature at which the axial tightness was established, and the value of the tightness, are written down on the test card.

When the correctness of the established axial tightness and its stability have been checked, the straddle gage leg is moved to one side, the nut of the draw-in holder of the device is loosened, and the gyromotor is taken off and put into a special package with its cover.

In some gyromotor designs the axial tightness is achieved by a special spring, supported on one side by the collar of a special sleeve and on the other side by a bearing nut turned into the gyromotor frame. The sleeve can move freely in the bearing seat and is pressed by the collar, with the force created by the spring, against the face of the outer ring of the ball bearing, which for its part moves under the effect of this force in the bearing seat of the frame, and which shifts the rotor to the side of the cover. Thus the spiral spring eliminates free play during the operation of the gyromotor and creates an axial tightness of the required value. In order to give rigidity to the springs, besides undergoing a heat treatment, they are subjected to constraining force treatment which consists in compressing the turns of the spring until they touch, and holding them in this position for 24 hours.

When the value of the axial tightness of the ball bearings is chosen, it is necessary to take account of the variation in the dimensions of the parts and units of the assembled gyromotor in operation, due to warming up, and of the operating ability of the ball bearings at the chosen tightness. An axial free play in the main supports of the gyroscope is inadmissible.

§76. CHECKING THE BALANCE OF GYROMOTORS

When the necessary tightness of the gyromotor ball bearings has been established, the imbalance of the assembled gyromotor is determined; this is done in a special frame described in Chapter 5, using the same balancing machine on which the rotor was balanced. The checking can also be carried out on a different balancing machine, provided that this is no less accurate than the machine on which the rotor was balanced. When checking the imbalance of the rotor in the assembled gyromotor, it must be noted that the accuracy of the balance will be different when the rotor is assembled with the gyromotor, regardless of how accurately the rotor may have been balanced in the frame. This is due to changes in the fit of the outer ring of the ball bearing, in the axial and radial clearances, and in the coaxiality of the fitting surfaces in the body and in the cover. There are a great many other factors affecting rotor balance in the assembled gyromotor.

Before checking the imbalance of the gyromotor, the sensitivity of the balancing machine is tested by the standard rotor method described in Chapter 5. When the sensitivity of the balancing machine has been tested, the assembled gyromotor is placed in its frame, and the voltage from a high-frequency generator is fed to the stator winding through the terminals of the machine. The gyromotor rotor is caused to rotate by pressing the starter button of the balancing machine; as soon as the number of rpm of the rotor exceeds the resonance frequency, the button is released and the voltage disconnected from the stator winding. The number of rpm of the rotor then decreases. The scale of the machine is used to test the imbalance at a number of rpm corresponding to the resonance frequency, first from the same side as the cover, and then from the same side as the body. The method is described in Chapter 5.

The magnitude of the imbalance of the rotor in the assembled gyromotor may be greater than when the rotor is balanced alone, but it must satisfy the technical specifications. If the imbalance of the rotor in the assembled gyromotor is greater than the admissible value, the motor must be disassembled. The rotor must be additionally balanced by itself in the frame, after which the gyromotor is reassembled, the tightness is adjusted and the imbalance of the rotor in the assembled gyromotor is checked. When the imbalance of the rotor has been checked, the gyromotors which have passed the test are packed up and taken to the checking-test station, where the 6-hour preliminary tests described in Chapter 7 are carried out.

Gyromotors whose parameters after the preliminary 6-hour tests prove to lie within the limit imposed by the technical specifications are checked on the balancing machine to establish that the rotor balance has been conserved. The imbalance of the gyromotors after the 6-hour tests is also checked in the same way as after assembly: first the sensitivity of the machine is checked, and then the balance of the rotor on the same side as the cover and on the same side as the body. The magnitude of the imbalance may be somewhat larger than before the test, but must still lie within limits laid down by the technical specifications.

If this check shows that the imbalance exceeds the admissible value, the gyromotor is disassembled, the reasons for the increased imbalance are established and the rotor is additionally balanced. When the causes of increased imbalance have been eliminated, the gyromotor is reassembled in the usual way. As a rule, the ball bearings are changed in gyromotors subjected to reassembly. The stability of the axial tightness during the 6-hour tests is determined for gyromotors which have passed the test and whose imbalance lies within the permis-

sible limits. For this purpose, the gyromotor is placed in the same device as was used to adjust the tightness. The leg of a minimeter is placed on a mark on the cover, the locknut and the bearing nut on the side of the cover are eased off, and the indications of the minimeter are read. The difference between the values indicated by the minimeter when measuring the tightness and those after the 6-hour tests may not exceed the specified values laid down for the type of gyromotor in question.

If the difference is significant, this indicates that the tightness has either increased or decreased while the gyromotor was working, and hence that the tightness is unstable. The factors causing the instability of the tightness must be found and eliminated.

The most usual factor causing a decrease in tightness is a partial unscrewing of the screwed joint of bearing nuts and screws which fasten the cover to the body. For this reason, particular attention must be given to the threads in gyromotors. The screw couplings of the bearing nuts with threads in the seats of the body and cover must therefore be worked in on assembly, which is brought about by screwing up and unscrewing the nuts repeatedly. The locknut must also be worked in. The preliminary work-in smooths out the burrs which arise on threading, and prevents them from crumpling when the nuts are screwed in. Attenuation must also be paid to tightening the screws holding the cover to the body. As we have said already, the screws must bite along the whole length of their threads.

Both the elimination of the axial tightness and its detection must be carried out when the gyromotors have cooled down to normal temperature. In those gyromotors where the tightness of the ball bearings has become smaller, the causes are established, and only when they have been removed are the gyromotors reassembled and tested.

§77. DISASSEMBLY

After the 6-hour tests, and checking of the axial tightness and imbalance, the gyromotors are disassembled. Before being disassembled, the gyromotors are wiped with a batiste cloth, set on a socket with their covers, and the bearing nut on the side of the body is loosened. The gyromotor is then turned on the socket with the cover uppermost, the screws holding the cover on are unscrewed from the body, the bearing nut is unscrewed, and the cover and stator are taken out of the catch of the gyromotor body by means of a special appliance (Fig. 126). The appliance is taken away, the bearing nut is screwed back into the seat of the cover, and the cover, stator and rotor, together with the ball bearing, are taken out of the body. The snap ring and balls are then removed from the inner ring of the ball bearing and immersed in a gasoline bath. The cover is then placed on the socket with

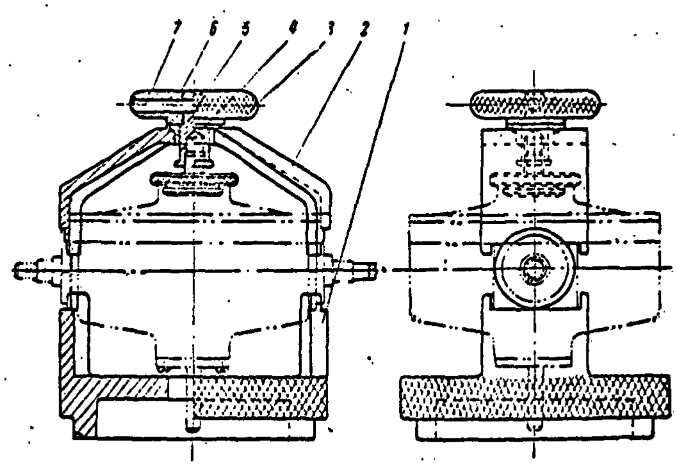


Fig. 126. Appliance for removing the cover from the body when dismantling the gyromotor. 1 and 2) Supports; 3) false nut; 4) bush; 5) screw; 6) handle; 7) pin.

the rotor pointing downwards, the bearing nut is removed from the cover and the cover is shifted by hand to the catch at the end and lifted off the rotor. The outer ring with the snap ring and balls is

carefully taken out of the seat of the cover with a special mandrel (Fig. 127), eased off the mandrel, and placed in a second gasoline bath. The bearing nut is unscrewed from the seat of the body, and the outer ring of the ball bearing is carefully taken out and laid in the first gasoline bath, the one where the snap ring and balls have been

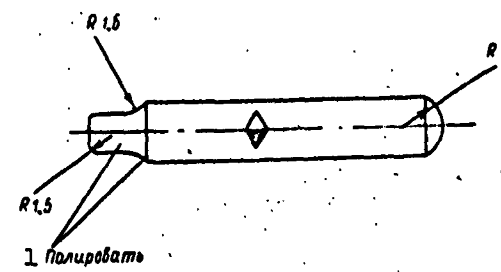


Fig. 127. Mandrel for extracting the outer ring of the ball bearing. 1) To be polished.

placed. The parts of the ball bearings are washed clean and then inspected for dregs left behind after washing, first with the naked eye, and then under a lens with 6-fold magnification. If metal particles are found in the dregs, the ball bearing parts are carefully examined closely under a binocular magnifying system. Attention is paid to the absence of hollows in the balls, scaling of metal on the races and other defects in all parts of the ball bearings.

The parts of the gyromotor are washed and wiped, and all the fitting surfaces and screwed joints are inspected. Parts which must be kept in the air for more than two hours are stored in a desiccator containing calcined silica gel.

The parts of gyromotors which have successfully passed the 6-hour tests and been dismantled are finally reassembled out of their original parts.

§78. FINAL ASSEMBLY

Before the gyromotors are finally assembled, the reliability of

the screws fastening the inner rings of the ball bearings onto the necks of the rotor axles is tested, and the screws are finally locked. The inner rings of the rotor are washed in gasoline, wiped and carefully inspected once more for nicks etc. under a lens with a 6-fold magnification. The rotor is then placed on the socket with the open side pointing upwards, the fitting surfaces of the cover are wiped with a cloth moistened with gasoline, and the cover and the stator are placed on the rotor. The sequence of operations throughout the subsequent assembly of gyromotors is the same as that in preliminary assembly.

In final assembly, particular attention must be paid to mounting and lubricating the ball bearings. Before assembly, all the parts of the ball bearings must be inspected once more with a lens having a 6-fold magnification to make sure that defects are absent. The lubricant must be applied in exactly measured quantities, for the influence exercised on the working of the gyromotor by too much lubricant can be just as bad as that due to too little. 30-40 mg of lubricant are applied when lubricating the snap ring and the balls of radial-thrust ball bearings with a bore of 5 mm, and a volume of lubricant equal to half that of the hollow chamfer is introduced into the bearing caps, the lubricant being uniformly distributed over the walls of the cap chamfer and above all the bottom of the cap.

In the final assembly, all screws fastening the cover to the body are painted with red nitro enamel, to prevent the screws working loose. The bearing nuts are also painted with red nitro at several points where they touch the body.

When they have been finally assembled, the gyromotors are tested for the tightness of the ball bearings, using a device described in the section on preliminary assembly; when finally assembled gyromotors

are being adjusted, however, the position of the bearing nut and locknut with respect to the cover after tightening is marked with a scriber, and both nut and locknut are painted with red nitro enamel together with the face of the cover.

When the tightness of the finally assembled gyromotors has been checked, the imbalance of the rotor is checked, the sensitivity of the balancing machine being tested beforehand with a standard rotor or standard gyromotor. The imbalance is checked at a number of rpm corresponding to the resonance frequency, both from the same side as the cover and from the same side as the body. If the degree of imbalance exceeds that established in the technical process, the rotor is additionally balanced by the method described in Chapter 5.

The determination of the axial tightness and the checking of imbalance in gyromotors after final assembly are final test processes, and hence these parameters are generally laid down and tested by a representative of the Technical Checking Division and by the fitter, and the data from the tests are entered on the test card or in the test journal.

After the imbalance has been tested, the gyromotors are sent to a check testing station for a final check on all parameters, as described in Chapter 7.

Manuscript Page No.	[List of Transliterated Symbols]
298	ЦИАТИМ = TsIATIM = Tsentral'nyy nauchno-issledovatel'skiy institut aviatsionnykh topliv i masel = Central Scientific Research Institute for Aviation Fuels and Oils
299	ш = sh = sharik = bearing ball
300	п = p = posadka = fit

Chapter 7

TESTS ON GYROMOTORS

§79. KINDS OF TESTS

The following tests are carried out in gyromotor production:

Preliminary tests are carried out after preliminary assembly. These consist in determining: a) ohmic resistance; b) resistance of the insulation; c) direction of revolution; d) speeding-up time of the gyromotor; e) amperage in the three phases; f) speed of revolution of the rotor; g) input; h) running-down time; i) overheating of the stator winding.

Besides the checking of these fundamental parameters, the gyromotors have to be run uninterruptedly for six hours at normal rpm in order to reveal defects in parts and units and to run in the balls to the ball races of the bearings. Each gyromotor is subjected to these preliminary tests which are carried out by workers in the technical checking division together with those in the workshop..

Routine tests are made after final assembly of the gyromotor following the same program as the preliminary tests (points c, d, e, f, h, i). The routine tests are carried out while the gyromotor runs uninterruptedly at the normal rpm for 3 hours in order to reveal definitely any defects of parts and units and to complete the running-in of the ball bearings. They are carried out by the workers of the technical checking division and each measurement is entered on the test card.

The checking tests are carried out by the workers of the technical

checking division on each finally assembled gyromotor that has passed the (6-hour) test preliminary and the 3-hour routine test. In this test, the quality of finish (external appearance), the ohmic resistance of the stator winding, the resistance of the insulation, the electrical strength of the insulation, the direction of revolution, the current, the speed of revolution, the running-down time and the residual imbalance are determined. Besides verification of the technical specifications under the listed points, the readings recorded in the course of the routine tests are taken into account.

If only one of the above-listed parameters of the gyromotor fails to satisfy the requirements of the technical specifications, the gyromotor is rejected. The results of the checking tests in the factory are entered on a rating plate (Table 12) which accompanies the gyromotor to the customer.

The <u>type</u> tests have to be made when a newly developed gyromotor is released, when production in another factory is approved, or when any important changes in design or manufacturing technique are introduced. Type tests do not necessarily include all the points of type tests, and they may be performed once in a period laid down by the technical specifications in series or mass production. For type tests, gyromotors are selected that have passed factory tests, from batches and in quantities laid down by technical specifications.

The results of the type tests on gyromotors are entered into special journals and records of type tests. In addition to workers of the technical checking division and of the laboratory, representatives of the customer participate in the type tests. The test records are the principal documents for the acceptance and approval of the gyromotor type and form the basis for further developments in testing series manufactured gyromotors.

TABLE 12

Rating Plate for the Gyromotor

Заводской № A Завод-изготовитель B
Напряжение, в C D № подшипников
Частота, гц E F Дата выпуска смазки
Дата выпуска гиромотора G H № паспорта на смазку

I № п. п.	J Наименование параметров	K Единица измерения	L По Т. У.	M Результаты испытаний	
				N заводских	O контрольных
1	Внешний осмотр (соответствие чертежам, качество сборки) . . .		P Соответственно		
2	Сопротивление обмотки статора в холодном состоянии:				
	R_{1-2}	Q ом			
	R_{2-3}	ом			
	R_{3-1}	ом			
3	Сопротивление изоляции . . .	R мегом			
4	Электрическая прочность изоляции	в			
5	Направление вращения		S По стр.		
6	Сила тока в фазах через 1,5 мин.:				
	a В 1-й фазе	а			
	b Во 2-й »	а			
	c В 3-й »	а			
7	Сила тока в фазах через 10 мин.:				
	a В 1-й фазе	а			
	b Во 2-й »	а			
	c В 3-й »	а			
8	Скорость вращения ротора . .	T об/мин			
9	Остаточный дебаланс { a на раб. об.	U Гсм²			
	b на рез. об.	Гсм²			
10	Время выбега	V мин.			
		W Дата испытаний Представитель ОТК			

A) Factory No.; B) producing factory; C) voltage, v; D) No. of bearings; E) frequency, cycles; F) date of lubrication; G) delivery date of gyromotor; H) No. of lubrication passbook; I) No.; J) denomination of parameters; K) units of measurement; L) according to technical specifications; M) results of; N) factory measurement; O) control check; P) conform; Q) ohms; R) megohms; S) see arrow; T) rpm; U) gf/cm^2; V) min; W) date of tests, representative of the technical checking division. 1) External inspection (conformity with design, quality of assembly); 2) resistance of stator winding in cold state; 3) resistance of insulation; 4) electrical strength of insulation; 5) direction of revolution; 6) amperage in the phases after 1.5 min: a) in the 1st phase; b) in the 2nd phase; c) in the 3rd phase; 7) amperage in the phases after 10 minutes: a) in the 1st phase; b) in the 2nd phase; c) in the 3rd phase; 8) speed of revolution of the rotor; 9) residual imbalance; a) at working rpm; b) at resonance rpm; 10) running-down time.

The above-listed order, kinds and points of gyromotor testing usually are laid down in the technical specifications and instructions

for the given type. Besides the order of tests and the acceptance of gyromotors, the order of design checking and technical documentation (including the order for checking the developed technological process) is shown in the technical specifications. The order of allowances for insignificant deviations from the design and technical specifications in the manufacturing process are laid down, as well as the order of variations of designs and the technological process.

General and special requirements, anticorrosive coatings and lubricants, testing methods, acceptance rules and requirements for the storing and packing of gyromotors are shown in the technical specifications.

The order of accepting materials, semimanufactured products and fastening parts has to be discussed in the general technical requirements for gyromotors. Methods of protection against screw joints becoming unscrewed, requirements as to permanent connections and as to the finish of the gyromotor surfaces are stated. The electrical, climatic, and mechanical requirements having to be satisfied in the operation and testing of gyromotors are shown in the special requirements.

§80. INSTRUMENTS FOR THE TESTING OF GYROMOTORS

Whatever kinds of tests are used, the checking and acceptance of gyromotors must be executed using instruments of the appropriate class of precision and be attested by certificates of inspection. Gyromotors are tested and checked at desks and panels furnished with electrical or other measuring instruments.

The principal instruments for making electrical measurements included in the equipment of these desks and apparatus for the testing of gyromotors, are ammeters, voltmeters, frequency meters, wattmeters, and stroboscopes.

In the checking tests and type tests for measuring the voltage of 3-phase alternating current, voltmeters with 0-50 v scales and maximum errors of 2.5% at frequencies of 400-500 cycles are used.

The currents are measured by means of ammeters with 0-1-amp scales and maximum errors of 2.5% at a frequency of 500 cycles.

The input at minimum voltage is measured by means of wattmeters with maximum errors of 2.5% at a frequency of 500 cycles.

The most frequently used instruments are alternating current instruments with thermoelectric, detector and electromagnetic systems. Hertz-Universal-type detector voltmeters of class 2, and the more precise D-525 type ones of class 0.5, developed by the "Tochelektropribor" factory for the calibrated frequencies of 400 and 500 cycles, are the most frequently used of all. E-51 type electrodynamic ammeters of class 1 and the more precise D-526 type ones of class 0.5 from the "Tochelektropribor" factory are used for the calibrated frequencies of 400 and 500 cycles.

To determine the speed of revolution of gyromotor rotors, the frequency of the 3-phase alternating current is measured with a basic error of 0.5% by means of a V-10 type tuning fork frequency meter of class 0.5 with a 495-505 cps scale. The other parameters of gyromotors are measured with an error of 2.5% by means of D-506/4 type frequency meter with a 450-550 cps scale.

Under normal conditions, the resistance of the insulation is measured with a M-1101 type megohmmeter, which ensures a nominal testing voltage of 500 v direct current. Its scale permits resistances of the order of magnitude 20 megohms to be measured with an error of $\pm 10\%$.

The resistance of the insulation at high relative humidities of up to $95 \pm 3\%$ is measured with a megohmmeter ensuring a nominal test

voltage of 100 v direct current with a scale allowing resistances as high as 2 megohms to be measured with an error of ±10%.

The ohmic resistance of the stator winding is measured with instruments subject to a maximum error of 1%. UMV-49 type Wheatstone bridges are usually used.

The electrical strength of the insulation is measured with an apparatus giving a nominal testing voltage of 500 v alternating current, a frequency of 50 cycles, and a minimum power of 0.5 kw. It is not desirable to use apparatus of higher power as too powerful a spark (occurring if the insulation breaks down even because of some casual and easily preventable negligence in assembling the gyromotor) may cause great and often irreparable damage in the gyromotor. When a high voltage source with a power of 0.5 kw is used, the breakdown of the insulation usually causes no damage. After detecting the position of the breakdown, and after removing its cause, the gyromotor can be passed as suitable for delivery subject to another routine test. The voltage is raised either continuously or in steps from zero to its nominal value, and is then reduced continuously or in steps to zero. The height of each step must not exceed 30 v.

The principal electrical connections of one of the devices for testing the strength of the insulation with alternating current are shown in Fig. 128. This device consists of a transformer 1, a variable resistor 4, a resistor 6, a voltmeter 7, an ammeter 5, a signal lamp 3, a switch 2, a plate 8 and a test chamber 9.

The transformer must have a minimum power of 0.5 kw. The variable resistor 4 allows the voltage to be continuously varied. The resistor 6 limits the amperage in the secondary transformer circuit. The minimum accuracy of voltmeters and ammeters must be of class 2.5. The scale of the voltmeter is graduated with respect to the resistor 6.

The plate is made of electrically conducting material to ensure a reliable electric contact with the body of the tested gyromotor. The construction of the chamber must permit gyromotor testing to be observed easily and safely. When the door of the chamber is opened, the testing device is switched off automatically.

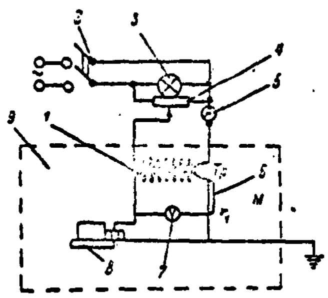


Fig. 128. Schematic electrical circuit for testing the strength of the insulation with alternating current.

The devices for measuring the speed of revolution of gyromotor rotors must permit measurements with a maximum error of ± 150 rpm. These errors are laid down in the technical specifications for the given type of gyromotor. For this purpose, ST-4 type electronic stroboscopes with 0-100,000 rpm scales or 1200-D type stroboscopes from the Dow firm are used.

The electronic stroboscopes consist of a master oscillator and a light pulse generator (a neon or mercury tube). The frequency of the oscillations of the master oscillator and, consequently, the frequency of the light pulses are tuned by switching the condenser on and off by means of regulating pulses (at rough tuning). Fine tuning is effected by varying the polarity of the thyratron grid. The light pulses may last for times from 5 to 10 μsec. The scale of the stroboscope is usually graduated in cycles and revolutions per minute.

§81. THE SIX-HOUR PRELIMINARY TESTS

After preliminary assembly, the gyromotors (with the axial tightness adjusted and with the rotor inspected for imbalance on a balancing machine) are put into a special casing and kept for 1-1.5 hours in the checking test station room. After this, the ohmic resistance of the stator winding is measured, for which purpose the phases of the winding are connected pairwise in turn to the terminals of a bridge. From the

readings of this bridge, the resistances of the phases and the resistance differences between the phases are determined. When the temperature of the surrounding air differs from +20° the resistance of the

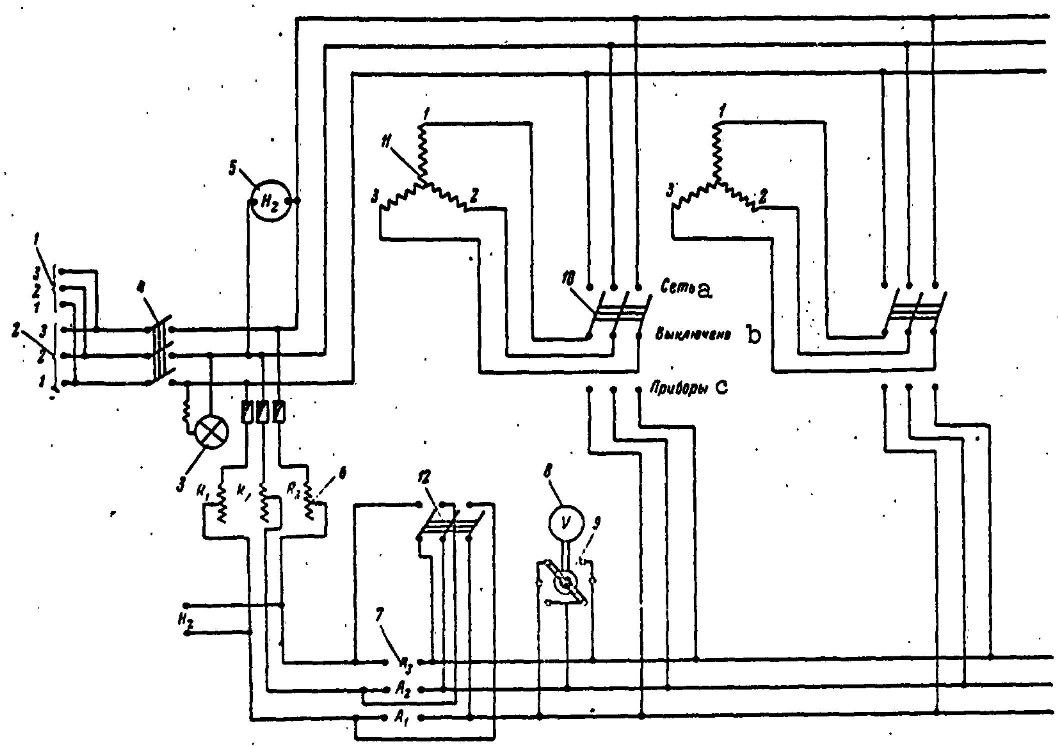


Fig. 129. Electrical circuit diagram of the desk for checking gyromotors. 1,2) Terminals of high-frequency generator; 3) lamp; 4) main switch; 5) frequency meter; 6) variable resistors; 7) terminals for ammeter connections; 8) voltmeter; 9) changeover switch of the voltmeter; 10) three-pole switch; 11) gyromotor windings; 12) ammeter switch. a) Line; b) off; c) instruments.

stator winding is computed from the equation

$$R_{20}=R_T\frac{255}{235+T}\ \text{ohms},$$

where R_{20} denotes the resistance of the winding at +20°; R_T is the measured value of the resistance at the temperature T; and T is the temperature in °C of the surrounding air at which R_T was measured.

Gyromotors that show differences between the stator winding resistance and the resistance as laid down in the design must not be

handed on for further tests.

After measuring the ohmic resistance of the stator winding, the resistance of its insulation and the resistance of the insulation of any current-carrying part of the gyromotor with respect to the housing are checked with a megohmmeter, which gives a direct current at 500 v when its crank handle is turned. In making the measurement, one terminal of the megohmmeter is connected to one end of the stator winding while the other end of the winding is connected to the gyromotor body. The resistance of the insulation is read on the megohmmeter scale. The resistances of the stator winding and of any current-carrying part with respect to the body must not be lower than the resistances fixed in the technical specifications for the given type. The duration of the tests must not be shorter than 3 sec. Gyromotors whose winding insulation resistances fail to satisfy the technical specifications are rejected.

Gyromotors whose ohmic resistance and insulation resistance are found to correspond with the technical specification are put on a special bench (a diagram of which is shown in Fig. 129) for a further check on the nominal data for the rolling of the ball bearings and for detecting possible defects.

The bench includes a casing with sockets for fixing down the gyromotors (which are fitted into them horizontally) and the stator windings of the gyromotors to be tested are connected in parallel with the bench circuit which is fed by a special high-frequency generator. The gyromotors are connected to the bench terminals by special ends or clips.

To check that the stator winding is properly connected to the corresponding bench terminals the running direction of the rotor can be observed through a hole in the body; this rotor must revolve clockwise

when one looks through the hole of the back wall of the gyromotor body.

On the bench the gyromotors are connected to the voltage one after another in a strictly determined order with intervals of at least 5 seconds. While these motors are running their remaining parameters are measured according to the technical specifications.

The Acceleration Time of the Gyromotor

Determining the time of acceleration involves starting a stopwatch at the instant when voltage is supplied to the gyromotor. After the gyromotor has operated for 4 minutes the amperage has to be measured in one of its phases. The currents are measured consecutively in all the gyromotors connected to the desk by inserting an ammeter into the circuit of each gyromotor in turn.

After the gyromotor has been running for 20 minutes the amperage is measured again in the same phase. The amperage found in the first measurement must not exceed that taken in the second measurement by more than 10%. If it differs by more than 10% the gyromotor is assumed not to accelerate properly and is rejected. The amperage in the gyromotors is measured in the same sequence as that in which the gyromotors were connected under voltage to the bench. A 5-second lapse between successive hookups of the gyromotors is necessary for measurement of the phase currents; this can be managed by connecting an ammeter into the winding phases with a three-pole knife switch.

Measurement of the Amperage in the Three Phases of the Gyromotor

In gyromotors, which usually accelerate for 20 minutes after being switched on, the amperage is measured in each of the three phases. For a fixed voltage the amperage must not be higher than that laid down in the technical specifications. Gyromotors in which the amperage is not consistent with that required are not admitted to further tests. The

causes for this type of flaw are exposed.

Speed of Revolution of the Gyromotor Rotor

The speed of revolution of the rotor is measured through one window opening into the gyromotor body after the amperage has been measured in each of the three phases. Before the number of rpm of the rotor is measured, the necessary voltage is adjusted using a voltmeter, as is the frequency, using a frequency meter (whose error must not exceed 5%).

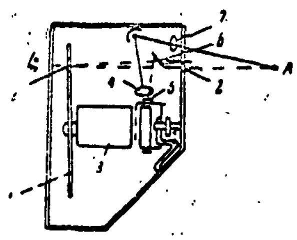


Fig. 130. Arrangement of the electro-optical-mechanical stroboscope.

The speed of revolution of the rotor is measured by means of a tachometric stroboscope (Fig. 130) in the following way: the stroboscope disk 1 with its viewing slit 2 is set in fast rotation at a constant speed by means of the electromotor 3. Before the second painting, a special form of spiral is mounted on the rotor as described in Chapter 5; a light beam from an incandescent bulb is directed at this spiral through the lens 4 to fall up upon the scale 5. An enlarged image of this scale is visible in the mirror 6. Thus the scale in the mirror and the rotor spiral illuminated through the lens 7 can be watched simultaneously through two opposite slits. By regulating the speed of revolution of the electromotor a coincidence is reached between the number of rpm of the stroboscope and that of the rotor; this is the case where the rotor seems to be stationary. At this moment the indication on the stroboscope scale is read.

In measuring the speed of revolution by means of an electronic stroboscope a light beam is directed onto the spiral mounted on the rotor, and, by turning a crank handle, the generator is adjusted to the required frequency at which the rotor appears to be standing still.

At this instant, the reading (in rpm) is taken from the scale.

Power Needed by the Gyromotor

The power input is measured not earlier than 20 minutes after the gyromotor has been set in operation at working voltage, by means of two wattmeters connected to the phase windings according to Aaron's scheme. During these power measurements, it is necessary to watch the readings of the voltmeter and of the frequency meter, which must remain within the limits specified by the technical specifications.

The gyromotors are run in during the first hour at normal voltage and frequency, and during the second hour at the maximum possible working voltage and the same frequency. The tests are alternated in this way for 6 hours. Some gyromotors are run in for 6 hours without variation of voltage and frequency.

The operation of each gyromotor is watched periodically during the process of running-in; the amperages are measured in each phase of running in with an ammeter, the body is felt in order to determine its heating, and the noise of the ball bearings is measured; for this purpose, one end of a small stick such as a pencil is applied to the frame at positions where the ball bearings are located and the other end is put to the ear. The noise must contain only a single tone, free from periodical jerks. A dull interrupted sound shows that the ball bearing is not clean; whistling sounds indicate that it is not sufficiently lubricated. In sounding the units with ball bearings, account must be taken of the individual working properties of the unit and of the character of the noise produced in its operation. With experience it is easily possible to detect machine units with ball bearings that are not working normally.

During the initial period of running in, the temperature of ball bearing units rises somewhat. When the ball bearing and the parts of

the unit have been manufactured and assembled accurately, this noise usually ceases after the gyromotor has been running for a certain time. The temperature of the unit must decrease and remain at a steady level. If, however, the temperature increases rapidly, the testing of the gyromotor must be interrupted and the cause of the temperature rise in the ball bearing unit must be found out.

When the gyromotor has been assembled correctly, the amperages in the phase windings are slightly increased at the beginning of the test, but in the course of further operation they must drop to a certain stationary value. If, however, they continue to increase during operation, the tests have to be interrupted and the cause of the gyromotor not operating normally must be found.

During the last hour before the tests come to an end, the amperage in each phase winding and the number of rpm of each gyromotor are measured again. The ohmic resistance of the stator windings is measured at the instant of their disconnection from the mains, this being necessary to determine the overheating of the stator winding.

Overheating of the Stator Winding of the Gyromotor

To determine the overheating, the ohmic resistance of the stator winding is measured on a bridge immediately after switching off the gyromotor; this measurement is made in the same phase winding as was measured cold, and the temperature of overheating is computed from the formula

$$T = \frac{R_{r\,1-2} - R_{x\,1-2}}{R_{x\,1-2}} (235 + t_1) + t_1 + t_2,$$

where R_{g1-2} is the resistance of the two phases of the stator winding, measured at the instant of switching off the gyromotor; T is the temperature of the overheating of the stator winding in $^{\circ}C$; R_{x1-2} is the resistance of the two phases of the stator winding measured before be-

ginning the gyromotor tests; t_1 is the temperature of the surrounding medium during measurement of the resistance R_{x1-2}; t_2 is the temperature of the surrounding medium during the measurement of the resistance R_{g1-2}.

The temperature of overheating must not exceed the value fixed by the technical specifications.

The Running-Down Time of the Gyromotor

The running-down time of the hot gyromotor is measured at the end of the 6-hour tests. For some types of gyromotors, however, the running-down is measured when the gyromotor is in a cold state. In this case, the gyromotors that have undergone the 6-hour tests are given at least 1.5 hours to cool down to the normal surrounding temperature. After this cooling the gyromotors are connected anew to the normal voltage consecutively at 5-second intervals. After 20 minutes of operation, the running-down time of each gyromotor is determined. The running-down is determined by accurately ascertaining the time at which the stator winding is disconnected and the time at which the rotor of the gyromotor comes to rest completely. In this way the length of time that the rotor continues to revolve without input of electric power will be equal to the running-down time of the gyromotor. The running-down of the rotor, which can be checked by testing the inertia of the revolution of the rotor, must lie between the limits of the minimum and maximum values prescribed in the technical specifications.

The running down characterizes the quality of the ball bearings, the quality of the lubricant and especially its penetration, the amount of the axial tightness of the ball bearings and the quality of assembly.

When there are metallic particles or other impurities in the ball bearings, the running-down time usually decreases. When the lubricant

is of low quality and, in particular, when it penetrates to a considerable extent, the running-down time also decreases.

At increased tightness or when the ball-bearing seats in the cover are askew relative to the seats in the body, the running-down time is reduced. When the tightness is reduced in the course of the running of the gyromotor, or when the tightness established initially is insufficient, the running down is considerably increased.

The running-down time is very characteristic for the quality of the gyromotor. It needs, therefore, to be carefully measured in the preliminary and other tests on the gyromotor.

After the determination of the rundown time, the gyromotor is allowed to cool off and the imbalance is measured for the number of rpm corresponding to the resonance frequency by means of a balancing machine whose sensitivity has previously been verified by comparison with a standard rotor. These measurements are carried out first on the cover side, then on the body side, following the method described in Chapter 6. If the imbalance reaches an extent greater than that allowed in the technical specifications, the gyromotor is dismantled, the rotor is specially balanced, and the gyromotor again undergoes the 6-hour preliminary testing. In the case of those gyromotors where the imbalance does not exceed that allowed in the technical specifications, the axial tightness is checked on a device described in Chapter 6.

The results of measurements are entered on the test card or in a special record. The gyromotors for which the parameters in all the checks during the preliminary tests lie within the required limits are dismantled, inspected and finally reassembled.

§82. THE THREE-HOUR ROUTINE TESTS

After the final assembly, and before the checking tests, the gyromotors undergo routine tests for 3 hours. The routine tests are car-

ried out on the same bench and in the same position as the preliminary 6-hour tests according to the points listed above.

When the stator windings are connected to the mains, the direction of revolution of each gyromotor is first checked visually. It must be clockwise when viewed from the body end. The gyromotors are switched on consecutively as in the preliminary tests, allowing a minimum time interval of 5 seconds needed for switching on and reading the ammeter.

The routine tests are performed continuously for 3 hours according to the program and the methods adopted in the preliminary tests at the voltage and the frequency indicated in the technical specifications for each type of gyromotor. Some types of gyromotors are tested at normal voltage and frequency during the first hour, at maximum voltage during the second hour and again at normal voltage during the third hour. The gyromotors are not switched off at the moment when the voltage fed to them is changed.

Gyromotors that do not meet the requirements of the technical specifications when undergoing the routine tests, have to be dismantled so that the defects can be found. In the subsequent reassembly it is permissible to exchange gyromotor parts and units.

After performing the 3-hour routine tests on the desk for the gyromotors cooled down to normal temperature, the imbalance of the rotor running at working speed is checked on a balancing machine having a sensitivity fixed according to the method described above. If imbalance of the rotor at the working number of rpm is greater than permissible the gyromotor has to be dismantled. The reason for the increased imbalance must be found, the gyromotor must be balanced additionally and then be assembled, after which the preliminary and then routine tests have to be performed again. The results of the routine tests are

entered on the test card or into the report.

§83. THE CHECKING TESTS

After undergoing the 3-hour routine tests, the gyromotor is subjected to the checking tests carried out by the workers of the technical checking division of the factory, with the following scope and sequence.

External Inspection

The gyromotor which has passed the preliminary and routine tests is subject to an external inspection first in the checking tests. In this inspection, the external and internal finish of rotor, body, cover, quality of mounting, state of fastening parts, reliability of permanent and nonpermanent joints are checked through a window in the body. The joints of the parts and units must be reliable: the screwed joints properly tightened, the screws secured from self-loosening, with the aid of an adhesive or nitro enamel. The screw heads and the nuts must be painted with red nitro enamel or with nitro glue in such manner that the enamel film over the part to be fastened and the screw head or nut is firm. When fixing the necessary tightness of the ball bearings, a red enamel stripe must be painted on the bearing nut screwed into the bearing seat of the cover, on the locknut and of the cover of the gyromotor. Inspection by the naked eye must not reveal any hollows, scratches or traces of corrosion. The marking of the output terminals of the stator winding must correspond to the drawing.

To test the play and the eccentricity of the pivots, the protecting linoxyn tube is removed from them, and the polished pivot necks and pivot centers are degreased. The pivots are rubbed with a batiste cloth moistened in gasoline, and dried in air. The play of the pivot necks is determined in the centers, using an indicator. The pivot centers are cautiously rubbed before testing. The jaw of the indicator

with a scale division of 0.001 mm is led up to one of the pivot necks and, turning the body with the pivots around the axis, the play of the pivot neck is determined; this play must not exceed the permissible value. To measure the eccentricity of the pivot necks, two indicators are applied simultaneously, whose jaws are led up to the necks of the two pivots. The indicators must have approximately equal errors. Turning the body through 360° about its axis, the readings of the indicators are noted. Testing with one indicator, initially the play of one neck is determined, marking the planes of maximum and minimum play. Then the play of the neck of the other pivot is measured, also marking the planes of maximum and minimum play. If the planes of maximum and minimum play coincide, the eccentricity of the pivot necks is equal to this play. If the planes of maximum and minimum play do not coincide, then the maximum plays are added or subtracted when computing the eccentricity depending on their position with respect to the planes of the pivot necks. The amounts of eccentricity and play must fall within the limits of tolerance.

After the determination of the play and eccentricity of the pivot necks, the gyromotor is taken from the centers and its profile dimensions are verified. The profile dimensions are verified with templets or a vernier caliper with a scale division of 0.05 mm. If the actual dimensions do not correspond to those prescribed the gyromotor is rejected. The pivots of the suitable gyromotors are degreased, dried in air and the whole length of the pivots is coated with TsIATIM-202 grease. After that, a protecting linoxyn tube is put on them. The body and the cover of the gyromotor are rubbed and put in special packing in which they are transferred to electrical parameter testing.

The Measurement of the Ohmic Resistance and of the Insulation Resistance

The measurement of the ohmic resistance of the stator winding and the other checking measurements must be performed at normal temperature and humidity.

The ohmic resistance of the stator winding of any two phases is measured as in the preliminary tests on a Wheatstone bridge. The insulation resistance of all current-carrying parts relative to the body is measured with a megohmmeter as described above in explaining the preliminary tests.

Checking of the Electrical Strength of the Insulation

The electrical strength of all current-carrying parts relative to the body is tested on an alternating-current device (see Fig. 128).

To measure the strength of insulation, the gyromotor is laid on a metal plate, with one feed wire leading to it from the high-voltage winding of the transformer of the device. The other wire of the high-voltage winding of the transformer leads to a special rod whose terminal is in contact with the output terminals of the gyromotor during the checking. After placing the gyromotors on the metal plate of the device, the door of the chamber is closed. Only then can the voltage be supplied, since the door has a safety device. By closing the switch of the device, a voltage with the frequency of 50 cycles is fed to the primary winding of the transformer. The terminal of the rod is connected to one of the output terminals of the stator winding and the test voltage is raised smoothly from zero to its nominal value. The full experimental voltage is maintained for 1 minute, and is then decreased smoothly to zero.

No breakdown of the insulation may occur during the test. A sudden increase in the amperage (as read on the ammeter) or a decrease in

voltage (as read on the voltmeter) are symptoms of an insulation breakdown in the gyromotor. After checking every gyromotor enclosed in the chamber the voltage is turned off with a switch, the door is opened, and the gyromotors are carefully taken out of the chamber one by one. The gyromotors that have been tested for the electrical strength of the insulation are placed on a special test console, where the remaining parameters are verified.

The following checking tests are performed on the test console: verification whether the direction of revolution is right, measurement of the amperage in the phases, determination of the speed of revolution and determination of the running-down time in the sequence and according to the method described when the preliminary tests were considered.

In the checking tests, the residual imbalance is determined after all the other tests have been made. As in the preliminary tests, the sensitivity of the balancing machine is checked beforehand.

The results of the checking tests are entered into the rating plate (Table 12) that is filled in for every gyromotor. The gyromotor reaches the customer with this rating plate.

§84. TYPE TESTS

Type tests of gyromotors are performed in the above-listed cases: a) if a new type is about to be released; b) if the design or a technological process or the material is changed and if in any of these cases they influence the operational characteristics of the gyromotors; c) before approval is given for the gyromotors to be produced in another factory; d) in the series manufacture of gyromotors (once a year, or at other times determined by the technical specifications for a given type).

In the cases mentioned under b) and c), the type tests need not

take account of every point.

The object of the type tests is: 1) to determine the conformity of a given type of gyromotor to the demands of the technical specifications according to which it is manufactured; 2) to make apparent the characteristics and parameters that are important from the point of view of their practical application; 3) to check that production is running correctly; 4) to make apparent the advantages of a new or modernized gyromotor by comparing them with similar existing designs.

For type tests, staff of the technical checking division select the gyromotors that have successfully passed the checking tests. The number of gyromotors to undergo type tests is usually laid down in the technical specifications. For the tests of durability, gyromotors are taken which have passed the checking tests but which were not subjected to type tests in respect of any parameters.

The type tests are performed according to the program of the checking tests. The gyromotors are tested additionally: 1) at increased temperature; 2) at reduced temperature; 3) under vibration; 4) at increased humidity; 5) with respect to overheating temperature; 6) with respect to durability.

The results of the type tests of the gyromotors are entered into the type test record. The results of the durability tests are recorded in a separate record.

The results of the type tests on gyromotors in series manufacturing are valid for the gyromotors manufactured from the moment of completion of the type tests data to the moment of completion of the following tests.

If the type tests show that one or several gyromotors fail to satisfy one of the demands of the technical specifications provided for these tests, the type tests of this gyromotor or of several gyro-

motors must be stopped and the gyromotors must be examined in order to find the causes of their abnormal operation. Twice the number of gyromotors are selected from the same series to undergo routine type tests.

The Tests at Increased Temperature

For type tests of gyromotors in a medium above the normal temperature, electrically heated thermostats are used, which make it possible to raise the temperature of the gyromotors under test to the prescribed level and to keep it there during the time of testing.

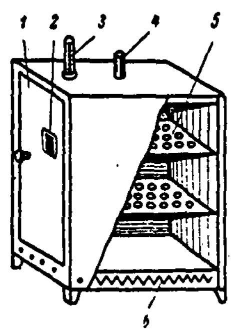


Fig. 131. Thermostat. 1) Doors; 2) window; 3) thermometer; 4) holes for the output terminals of the windings; 5) rack; 6) spiral coil.

Such a thermostat is shown in Fig. 131. The thermostat must have such dimensions as to leave a gap of not less than 50 mm between its walls and the gyromotors under test. The thermostat is fitted with a thermometer or with a thermocouple having a maximum error of $+0.2^{\circ}$. The limits of the temperature measurements must correspond to the temperatures at which the gyromotors are tested according to the technical specifications. The thermometer has a test chart with correctional tables. In testing the gyromotors at an increased temperature, the output terminals leading out through holes in the thermostat are connected or soldered to the terminals to which the stator winding is connected. The gyromotors to be investigated are placed on the racks inside the thermostat. The output terminals from each phase are led out to a desk where an ammeter of appropriate precision can be inserted into each phase. The gyromotors remain for 2 hours in the thermostat at the temperature necessary for the given type of gyromotor. After that, the working voltage is fed at normal

frequency to the stator windings. The amperage of the input current is measured in each phase after 4 minutes of operation, and then 10 minutes after switching on the gyromotor. The measurements are performed in each phase of the gyromotor by inserting ammeters into the corresponding phases on the desk. The gyromotor is assumed to have withstood the tests at increased temperatures if the currents in each phase after 4-10 minutes' operation correspond to those indicated in the technical specifications.

Tests at Reduced Temperature

Cooling devices with test chambers are used for testing gyromotors at reduced temperature. The main arrangement of the device is shown in Fig. 132.

The device consists of a chamber, a compressor, a condenser, and a pipe with a throttle valve. The inside of the test chamber is shielded from the influence of the external temperature by insulation. The insignificant amount of heat that penetrates through the insulation, and also the heat given off by the gyromotors in the test chamber, is carried off by a cooling refrigerant evaporating in the evaporator. The low temperature in the evaporating chamber is attained by means of a compression refrigerator, whose principle of operation can be deduced from the figure. From the condenser, the liquid refrigerant (Freon No. 12 is usually used as the refrigerant) flows under the pressure of condensation to a regulating valve where it is throttled to a

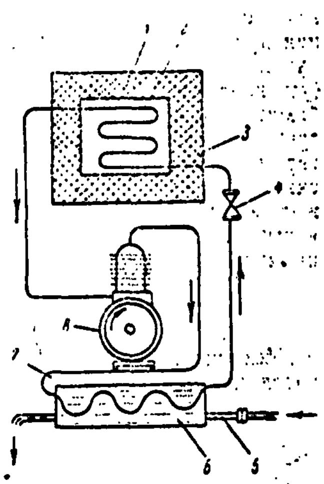


Fig. 132. Diagram of the cooling device. 1) Chamber; 2) evaporator; 3) insulation; 4) throttle valve; 5) cooling water; 6) condenser; 7) refrigerant; 8) compressor.

low pressure, and vaporizes in the evaporator due to the addition of heat. The vapor is drawn off continuously by a compressor, compressed and then reliquefied in a condenser by withdrawing heat with water. In this way, the inside of the test chamber is cooled by circulating the refrigerant. The device is fitted with automatic instruments which automatically cool the test chamber, maintain the necessary temperature for testing the gyromotors, and record the temperature on paper tape.

The gyromotors are placed in the chamber and their terminals are connected to leads which pass out through openings in the chamber walls. The leads are connected to the terminals of a high-frequency generator placed on the desk. The circuit of this desk is such that an ammeter can be connected into any phase of the stator winding of any gyromotor to measure the amperage in the phase during the tests. When the gyromotors in the chamber are arranged and connected up to the desk, the chamber door is hermetically sealed. The compressor of the device is switched on, and the temperature in the chamber is reduced to that indicated in the technical specifications for the given type of gyromotor. The gyromotors are kept at this temperature for 2 hours, then the stator windings are connected into the circuit of the high-frequency generator, attaining the necessary voltage by means of a variable rheostat and voltmeter inserted into the circuit. Ten minutes after insertion, and then after 20 minutes of operating the gyromotors, the amperage is measured in each phase of the gyromotor. At low testing temperatures, the rotors of some gyromotors begin to revolve only 10 minutes after the voltage has been fed to the stator winding. The current consumed by the gyromotors is greatest when they are started. From this amperage, and from the accelerating time, conclusions are drawn as to the quality of lubrication of the ball bearings, the axial tightness, the fit and accuracy of the connections between

the units and the presence of skewing in their assembly.

In order to determine the accelerating time, a stopwatch has to be started at the moment when the necessary voltage from the high-frequency generator is fed to the gyromotor placed in the chamber. When the gyromotor has been operating for 10 minutes, the amperage has to be measured in each of the three phases. Then, when the gyromotor has been operating for 20 minutes, the amperages are measured again. The amperages obtained in the first measurement must not exceed those obtained in the second measurement by more than a determined quantity which is established for each type of gyromotor. If this is not fulfilled it is assumed that the gyromotor does not satisfy the prescribed requirements. If the currents on starting or during operation after the gyromotor has been started are higher than the tolerances indicated in the technical specifications for the given type, the gyromotor is assumed not to have withstood the test at reduced temperature. The gyromotor is not subjected to further tests. The reasons for inadmissibly high amperage are investigated thoroughly.

Tests Under Vibration

The mechanical tests of gyromotors under vibrations are performed on the table of a vibration device. The gyromotors are placed vertically in supports. The investigation of a gyromotor whose rotor axle is vertical is most severe as the stresses due to the weight of the rotor are transferred to one ball bearing and to threaded joints.

Before the test, the table of the device is preadjusted to the necessary amplitude and frequency for an equivalent load equal to the weight of the gyromotor to be tested. Cables through which the voltage from a high-frequency generator is fed to the stator windings are connected to the terminals of the gyromotor. When the gyromotor has been operating for 4 minutes the electromotor of the vibration device is

switched on. The duration of the test, the amplitude and the frequency of the vibration are given in the technical specifications.

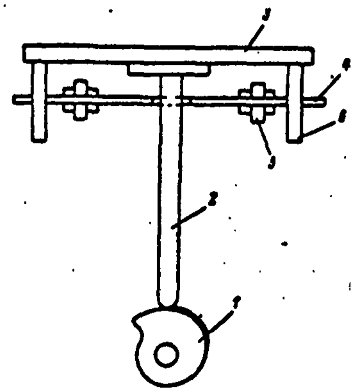


Fig. 133. Diagram of the vibration device. 1) Cam; 2) rod; 3) table; 4) frame; 5) regulator of the vibration amplitude; 6) guides.

When the appointed time has expired, the vibration device is stopped and the stator windings of the gyromotor are switched off. When the rotor has stopped completely, the gyromotor is removed from the device and subjected to the test according to the points of the checking tests. In external inspection, attention is paid to the quality of the screwed joints and other connections. They must not have been damaged.

While their external appearance is being inspected, the gyromotors are placed in a horizontal position in the socket of the testing desk. In accordance with the phase markings the stator windings are connected to the terminals of the desk so that the rotor revolves clockwise when viewed from the body side. On the desk, the amperage in each phase, the speed of revolution of the rotor, the running-down time at normal frequency and the voltage are inspected (according to the method described in the investigation of the preliminary and checking tests). The values found must not differ from the results of the checking tests. To determine the eccentricity of the rotor after the test under vibration, the gyromotor is placed on a balancing machine and the imbalance of the rotor at working number of rpm is ascertained by the method described above. The imbalances on the cover side and on the body side must not be greater than those found in the checking tests.

<u>Tests at Increased Humidity</u>

The tests at increased humidity are performed in a hygrostat. The

hygrostat consists of a thermally insulated chamber with tightly closing doors and with glass windows in the lateral walls for observing the processes inside the chamber. The volume of the chamber must be at least double that occupied by all the gyromotors investigated simultaneously. On the chamber bottom, a metallic pan is placed into which fresh or salted water (sea water) is poured up to a minimum height of 40 mm. The surface area of the water level in the hygrostat must be at least 20% greater than that of the horizontal projection of all the gyromotors to be investigated. The lower part of the gyromotors must be at a distance of approximately 200 mm from the surface of the water.

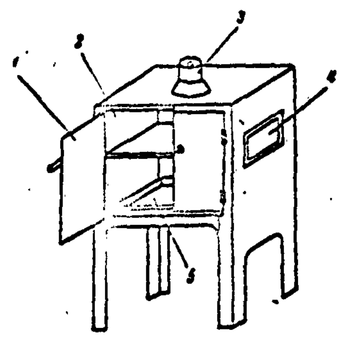


Fig. 134. Hygrostat. 1) Door; 2) chamber; 3) ventilator; 4) observation window; 5) bottom plate.

The humidity is measured by means of a psychrometer placed in the interior of the hygrostat at a height of approximately 300 mm above the level of the water. Alternatively the humidity can be measured using two thermometers. In this case the bulb of one thermometer is wrapped in a gauze whose ends are immersed in a vessel containing water. In other respects the moisture is determined as in the measurement using a psychrometer.

In order to attain a maximum uniform temperature and moisture content in the hygrostat, it is recommended to protect it by thermal insulation and to agitate the air within the hygrostat by means of a ventilator placed in the upper wall of the chamber.

From each gyromotor put into the hygrostat, two wires are led out: the first wire (having a minimum resistance of 100 megohms) is connected to one of the phases of the gyromotor and the second to its body.

When the gyromotors are laid on the rack the wires are led out through openings of the chamber; thereupon, the hygrostat is closed and the gyromotors put into it are kept there for the length of time fixed in the technical specifications at a relative humidity of 95 ± ± 3% and at a temperature of +20 + 5°C.

After the prescribed time, without taking the gyromotors out from the hygrostat, the resistance of the insulation of the current-carrying parts of the gyromotor with respect to the body is measured; for this purpose, the wires coming out from the hygrostat from one of the phases, and the wires connected to the frame of each of the tested gyromotors are connected to the terminals of a megger developing 100 megohms. The value of the resistance of the insulation is read from the scale of the megohmmeter at least 3 sec after beginning to turn the handle; the value of the resistance of the insulation must correspond to that laid down in the technical specifications.

After the resistance of the insulation has been checked, the cover of the hygrostat is opened and the gyromotors are taken out of it. These gyromotors whose resistance has satisfied the test are placed on the testing desk and the amperage in each phase, the speed of revolution of the rotor and the running-down times at normal voltage and frequency are checked using the methods and instruments described in the discussion of the preliminary tests. The measured quantities must not be different from the results of the checking tests.

The Determination of the Overheating Temperature

The temperature of overheating of the stator winding of the gyromotor is determined by the resistance method, which consists in determining the temperature from the variation of the ohmic resistance on heating. This method gives the average temperature of the stator winding, which, of course, is lower than that of the hottest point of the

winding. The average temperature of the winding as measured by the resistance method usually is lower than its highest temperature by 8-10° on the average. To determine the temperature of overheating of the stator winding, the ohmic resistances of two phase windings are measured at normal temperature. For this purpose, the gyromotors must be disconnected from the feed line for not less than 1 hour at the same temperature as that at which the ohmic resistance is measured, i.e., at normal temperature. When the ohmic resistance of the stator winding has been measured, the gyromotors are placed on the testing desk and the stator winding is connected to the terminals of the desk, and supplied with an increased voltage of normal frequency. The gyromotors must operate continuously for 3 hours under such conditions.

When the gyromotors have been operating for 3 hours, they are switched off one by one, and immediately afterwards the ohmic resistance of the same two phases of the stator winding is measured.

A necessary condition for correct determination of the overheating temperature is that the same bridges (with the identical connecting cables) should be used for measuring the resistance in the cold and in the hot state.

If this condition is not fulfilled, large errors may arise in the determination of the overheating temperature even if the bridge in the second measurement is used more exactly.

The value of the overheating temperature is determined according to the formula given in the discussion of the preliminary tests.

Test of the Longevity of Gyromotors

The gyromotors used for the longevity type tests have passed the checking tests. They are taken from the set of gyromotors selected for the type tests with respect to all the remaining points. The number of gyromotors selected for the tests of longevity and duration of opera-

tion is laid down in the technical specifications for the given type.

The aim of testing the longevity of a gyromotor (as of the type tests with respect to the other points) is to check the correspondence of a given type of gyromotor with the requirements of the technical specifications according to which it is manufactured after running it under conditions similar to operation conditions.

The component that mainly determines the possible duration of operation of the gyromotor is the bearing unit and especially the ball bearings. This necessitates always endeavoring to approximate the conditions under which the longevity of gyromotors is tested to the normal conditions of their operation in the corresponding devices.

The tests must be performed in a room at normal temperature with continuous ventilation to provide suitably clean air. If no such room is available the measurements are performed under a glass dome, under which there must always be a small excess pressure so that the surrounding dusty air cannot be drawn in under the dome.

In the longevity tests, the gyromotors are placed on the testing desk in a horizontal position, spaced in such a way that each of them is provided with an undisturbed stream of air. To make it possible to measure the speed of revolution and the running-down time, the inspection windows are closed with transparent material.

The stator windings are connected to the corresponding terminals of the desk and a normal voltage at the normal frequency for the given type of gyromotor is fed to them.

The starting time of the gyromotors and the number of operating hours are written down in a special record. The gyromotors must operate uninterruptedly for not less than 4 hours, and not more than 23 hours in tests that last all day long.

Since the ball bearings are the principal units limiting the ef-

ficiency and the longevity of a gyromotor, special attention has to be paid to the state of the bearings in the process of testing.

The factors noticeable in the operation of the bearing unit are the temperature of the ball bearings and the kind of noise they make. If, in the course of testing, it is found that the temperature of the bearing unit becomes excessively high, or that too much noise arises in the operation of the ball bearings, these deficiencies are entered in the record and the gyromotor is inspected.

As any inaccuracy of operation of the bearing unit increases the amperage consumed, the amperages are measured periodically in each phase. In the case of a significant increase of amperage the gyromotor is stopped and is assumed not to have withstood the type tests for longevity. The reasons for the increased consumption of electrical power are traced.

The heating of the bearing unit can be caused by the ball bearing becoming contaminated with foreign particles, by contamination of the lubrication, by excess or lack of lubrication, by defective mounting, by excessive tightness of the ball bearings, by destruction of parts of the ball bearings and so on.

An abnormal noise in a ball bearing can be caused by its contamination, by damage of the working surfaces or by a broken snap ring scratching on the rings.

After the gyromotors have operated for the necessary time they are stopped and allowed to cool down to the normal temperature, whereupon the following are checked: external appearance, amperage in each phase, speed of revolution of the rotor, running-down time, residual imbalance, state of parts and units on dismantling.

The inspection of gyromotors according to the points listed above is performed using the instrument, the apparatus and the method de-

described in the discussion of the preliminary and checking tests. The results must correspond to those found in the checking tests.

During dismantling, attention must be paid to the state of lubrication and to the completeness of the parts of the ball bearings. The results of the longevity tests on the gyroscopes are drawn up as a record.

If it is discovered during the type tests that one or several gyromotors do not satisfy one of the requirements of the technical specifications, the type tests of this or these gyromotors must be broken off, the tests of the other gyromotors must be continued.

A gyromotor that has not withstood the type tests must be investigated in order to discover the reasons for its abnormal operation.

The results of the investigation are centered in the record with notes as to the reasons for the disturbance of the operation of the gyromotor. For routine type tests, twice the number of gyromotors is taken. If consistent with the client's wishes, the routine type tests need only be carried out for those points which were not in order during the first type test.

§85. PACKING THE GYROMOTORS

The gyromotors which have withstood the checking tests, together with the filled-in rating plates are transferred in a container to a room for individual packing in cases made either or ordinary cardboard or of cardboard with a corrugated inner layer. The rooms in which the gyromotors are prepared and packed must be dry and heatable. The relative humidity of the air in them may be 45-70%, and the temperature between +10 and +30°. The room is furnished with benches intended only for preparing and packing gyromotors. In the room itself and in the neighboring rooms no alkalis or acids or similar materials may be stored.

Before packing, the observation windows in the body of the gyro motors are stopped up; the gyromotors are rubbed with a batiste cloth soaked with gasoline. The damaged spots are retouched and the pivots are protected. For this purpose the pivots are first degreased with a batiste cloth soaked with gasoline; after drying, the pivots are coated by means of a brush with TsIATIM-202 grease and wrapped in tissue paper or wax paper, and then in nonhygroscopic paper; they are laid in cardboard boxes with lids on which the number of the gyromotor is written. The boxes are tied up with string. Furthermore, the boxes with the gyromotors are packed in metal cases in which moisture-absorbing cartridges with silica gel are placed. The boxes must not shift within the case. The case is closed by a lid, with a small hole drilled in its center beforehand; the lid is soldered to the container in order to render the packing of the gyromotors airtight. The airtightness of the case is checked by applying an excess pressure of 0.1-0.3 atmospheres inside it through the hole in the lid, into which an adapter is fitted connected by a rubber tube to the air supply. The case is submerged in a tank of water and the surface of the water is observed. If air bubbles appear on the water surface, this means that the container is not airtight. The place where the bubbles come from is marked and specially soldered up. When no bubbles appear on the surface of the water, this indicates that the packing of the gyromotors is completely hermetic. After the airtightness of the case has been checked, the hole in the lid is soldered up. The cartridge with silica gel absorbs whatever moisture remains inside the case after the hole in the lid has been soldered up.

The cases containing the gyromotors are stored on racks in clean, dry storerooms with ventilation and heating.

The metal cases containing the gyromotors intended for delivery

are packed additionally in wooden crates made of planks or plywood. On packing, wood fiber is laid in a compact layer on the bottom of the wooden crate. The rating plate and packing list are wrapped in paper and then in parchment and are attached to the lid of the metal case; this case is put on the wood fiber in the wooden crate. On the top and on the sides of the metal case, the whole space is packed with wood fiber, up to the level of the lid. The wood fiber is compressed by hand without moving the metal case. Thereupon, the lid is nailed onto the crate. A label is put on the side walls of the crate. A circle 50 mm in diameter surrounding an arbitrary index (letter) is affixed in the top left corner. The serial number of the packing crate of the delivered series is marked in the upper part of the label; the right-hand side is marked with a picture of a glass, the top of which must correspond to the top of the crate. Above the glass there is an inscription "Top" and an arrow pointing to the up-side of the crate. In the center, under the number of the crate, are the inscriptions "Care, do not tilt," "Do not store in the crate." On the right-hand side, below the "glass," the weight of the crate is given: "Gross weight, kg."

Each inscription and picture on the crate must be painted clearly, accurately, with black paint using a stencil, with the exception of the inscription "Care, do not tilt," which has to be painted in red. The seals are fastened with wire threaded through specially drilled holes in the corners of the crate, fastened with staples, and encircled with red paint.

As a rule, the packed gyromotors are transported to the railway stations or airports in covered trucks. If open trucks are used the containers must be carefully covered with a tarpaulin. On the railway, the crates containing the gyromotors must be transported in covered cars. No acids, alkalis and similar materials may be transported in

the same car.

Manuscript Page No.	[List of Transliterated Symbols]
330	г = g = goryachiy = hot
330	х = kh = kholodnyy = cold
335	ЦИАТИМ = TsIATIM = Tsentral'nyy nauchno-issledovatel'skiy institut aviatsionnykh topliv i masel = Central Scientific Research Institute for Aviation Fuels and Oils

REFERENCES

Avtomatizatsiya i mekhanizatsiya protsessov proizvodstva v priborostroyenii [The Automation and Mechanization of Production Processes in Instrument Building], Mashgiz [State Scientific and Technical Publishing House of Literature on Machinery], 1958.

Andrianov, K.A., Rakitskaya, M.S. and Brelkov, A.G., Elektroizolyatsionyye kompaundy na osnove poliefirnykh smol [Electric Insulation Compounds Based on Polyester Resins], Vestnik elektropromyshlennosti [Herald of the Electrical Industry], 1956, No. 2.

Baykov, A.I., Tsentrobezhnoye lit'e alyuminevykh splavov i ikh liteynyye svoystva [Centrifugal Casting of Aluminum Alloys and Their Foundry Properties], Mashgiz, 1950.

Bel'kevich, Ya.P., Rukovodstva po spektral'nomu analizu metallov [Handbook on Spectral Analysis of Metals], Sudpromgiz [State All-Union Publishing House of the Shipbuilding Industry], 1950.

Volotov, V.Ye. and Popov, N.N., Ustanovka dlya izmereniya vibratsii podshipnikov kacheniya [Device for Measurement of Roller-Bearing Vibrations], Izmeritel'naya tekhnika [Measurement Technique], 1957, No. 4.

Budulya, P.N., Tekhnologiya liteynogo proizvodstva [The Technology of Foundry Production], Metallurgizdat [State Scientific Publishing House for Literature on Ferrous and Nonferrous Metallurgy], 1956.

Bulovskiy, P.I. and Povalyayev, A.B., Tekhnologiya sborki elektroizmeritelnykh priborov [Technology of the Assembly of Electric Measurement Devices], Oborongiz [State Publishing House of the

Defense Industry], 1955.

VNITOL [All-Union Scientific Engineering and Technical Society of Foundry Workers], Lit'ye pod davleniyem [Die Casting], Mashgiz, 1955.

VNITOL [All-Union Scientific Engineering and Technical Society of Foundry Workers], Tsentrobezhnoye lit'ye [Centrifugal Casting], Mashgiz, 1955.

Vorontsov, S.P. and Mayorov, S.A., Pribornyye sharikopodshipniki [Instrument Ball Bearings], Oborongiz [State Publishing House of the Defense Industry], 1951.

Grammel', R., Giroskop, yego teoriya i primeneniya [The Gyroscope, Its Theory and Uses], Volumes 1 and 2, IIL [Foreign Literature Publishing House], 1952.

Zholdak, S.A., Lychagin, Ya.Ya. and Popov, V.S., Tekhnologiya izgotovleniya elektroelementov dlya elektroavtomaticheskikh ustroystv [Technology of the Production of Electric Elements for Automatic Electrical Devices], Oborongiz, 1959.

Kovvi, K.G. and Plyatskiy, V.M., Preduprezhdeniye porokov v otlivkakh iz tsvetnykh splavov [The Prevention of Defects in Castings Made of Nonferrous Alloys], Mashgiz, 1953.

Kolesnikov, N.V., Staticheskaya i dinamicheskaya balansirovka [Static and Dynamic Balancing], Mashgiz, 1954.

Ksenofontov, B.M., Lit'ye metodom vsasyvaniya [Casting by Suction Method], 1952.

Moskovskiy, M.I., Tekhnologiya elektromashinostroyeniya [Electrical Machinery Construction Technology], Gosenergoizdat [State Power Engineering Publishing House], 1947.

Nikolay, Ye.L., Giroskop i nekotoryye yego tekhnicheskiye primeneniya [The Gyroscope and Certain of its Technical Applications], Gos-

tekhizdat [State Publishing House of Theoretical and Technical Literature], 1947.

Novikov, M.P., Sborka mashin i mekhanizmov [Assembly of Machines and Mechanisms], Mashgiz, 1951.

Ogloblin, A.N., Tekhnologiya tokarnogo dela [The Technology of Lathe Working], Mashgiz, 1950.

Oleynik, Ya., Primeneniye vyrubnykh shtampov iz tverdykh splavov v elektrotekhnicheskom proizvodstve [Use of Punch and Die Sets Made of Hard Alloys in Electrical Engineering Industry], Vestnik elektropromyshlennosti [Herald of the Electrical Industry], 1957, No. 11.

Pavlov, B.A., Aviatsionnyye giroskopicheskiye pribory [Aircraft Gyroscopic Instruments], Oborongiz, 1954.

Pavlov, V.A., Osnovy konstruirovaniya giroskopicheskikh priborov [Fundamentals of the Design of Gyroscopic Instruments], Oborongiz, 1946.

Pribory dlya kontrolya podshipnikov kacheniya [Instruments for Inspection of Antifriction Bearings], Mashgiz, 1957.

Progressivnaya tekhnologiya priborostroyeniya [Progressive Technology of Instrument Design], No. 1 and 3.

Rabiner, Ye.G., Montazh, demontazh i ekspluatatsiya podshipnikov kacheniya [Installation, Dismantling and Use of Antifriction Bearings], Mashgiz, 1951.

Serebrovskiy, V.B., Kachestvo poverkhnosti detaley mashin [Surface Quality of Machine Parts], Mashgiz, 1957.

Spravochnik mashinostroyeniya [Machine Building Handbook], Volumes 2, 6, 7.

Tekhnicheskaya entsiklopediya [Technical Encyclopaedia], Vol. 5, 1937.

Fedoseyev, D.N., Proyektirovaniye tekhnologicheskikh protsessov

sborki priborov [Planning the Technological Processes of Instrument Assembly], Mashgiz, 1957.

Fel'dman, S.S., Pretsizionnoye lit'ye [Precision Casting], Mashgiz, 1950.

Shitikov, B.V., Dinamicheskaya balansirovka rotorov [Dynamic Balancing of Rotors], Transzheldorizdat [State Publishing House for Railroad Transportation Literature], 1951.

Shkil'ko, G.Ya., Ob izgotovlenii korotkozamknútykh obmotok rotorov asinkhronnykh elektrodvigateley [The Production of Shunt-Wound Coils for Electric Induction Motors], Vestnik elektropromyshlennosti [Herald of the Electrical Industry], 1956, No. 5.

Eydes, I.G. and Kulakov, V.A., Sborka schetno-reshayushchikh mekhanizmov [The Assembly of Computer Mechanisms], Sudpromgiz, 1953.

Bassett, P.R., Quantity production of gyro instruments, "Mechanical Engineering," 1941, Vol. 63.

H.L.H., Machinery operations on the Sperry gyrocompass, "Machinery," 1944, Vol. 65.

Horton, H.L., Sperry gyrocompass dependable instrument of navigation, "Machinery," 1943, Vol. 50.

Mistron, C.A., Compass manufacture typifies diversity of Sperry operations, "Machinery," 1954, Vol. 60.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE	Nr. Copies
HEADQUARTERS USAF	
AFCIN-3D2	1
ARL (ARB)	1
OTHER AGENCIES	
CIA	1
NSA	6
DIA	4
AID	2
OTS	2
AEC	2
PWS	1
NASA	1
ARMY (FSTC)	3
NAVY	3
NAFEC	1
PGE	12
RAND	1
AFCRL (CRXLR)	1
SPECTRUM	1

MAJOR AIR COMMANDS	Nr. Copies
SAC (DICC)	1
AFSC	
SCFDD	1
DDC	25
TDBTL	5
TDBDP	2
TDGS	1
AEDC (AEY)	1
SSD (SSF)	2
APGC (PGF)	1
ESD (ESY)	1
RADC (RAY)	1
AFMDC (MDF)	1
AFWL (WLF)	1
AFMTC (MTW)	1
ASD (ASFA)	2